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A Summary of the Current Research

Program 7/1/65 and Preliminary

Report of Progress for 7/1/64 to 6/30/65

FOREST SERVICE

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This research progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between July 1, 1964, and June 30, 1965. This progress report was compiled in the Forest Service, U. S. Department of Agriculture, Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D. C.

July 1, 1965

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ROCKY MOUNTAIN STATION

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INTRODUCTION

This report summarizes progress during the past year in the forestry research program of the Department of Agriculture. Included is research carried on directly by Department scientists and that done cooperatively with other agencies. A summary of new information for each subject matter area is followed by a list of pertinent publications. The report concludes with a tabulation of currently active research projects.

The Department's research program provides the basis for management of the National Forests and National Grasslands by the Forest Service. It furnishes the technical base for protecting, developing and utilizing the resources of forest and range lands administered by other Federal agencies. And it contributes in large measure to the fund of knowledge on which depends effective management of all the Nation's forest lands and the utilization of forest products.

The National Forestry Research Advisory Committee annually reviews the forestry research of the Department of Agriculture. Progress during the past year and plans for the year ahead are discussed. The aim is to concentrate available resources on the more pressing problems and at the same time maintain proper balance toward achieving long-range objectives. Coordination of research efforts receives attention.

Research undertaken directly by Department scientists is conducted at the national headquarters, Washington, D. C. ; at the Forest Products Laboratory, Madison, Wisconsin; at ten Regional Forest Experiment Stations which carry out projects at a number of locations throughout the United States; and at the Institute of Tropical Forestry in Puerto Rico. Most of the research is headquartered on or near the campuses of colleges and universities. There are 350 active projects requiring about 1, 000 man-years of professional effort.

Forestry research is also in progress at a total of 59 state institutions under the McIntire-Stennis Cooperative Forestry Research Program and the Hatch Program, both administered by the Cooperative State Research Service. There are 197 current projects under the McIntire-Stennis program and 264 projects under the Hatch program. In 1964-65, 41 of the 59 state institutions had also filed project descriptions of their non-Federally supported research in forestry with CSRS, totaling 387 projects. Within the Hatch program, approximately 60 of the forestry projects contribute to twelve master projects which are organized on a regional basis. These regional master projects offer the advantages of cooperative planning and execution of research on problems of shared concern, and of regular exchange of results.

Department research effort extends from the initial development of information to its application. Examples from the past year follow:

Twelve-year results show adaptability of hybrid pine. Hybrids, being new genetic combinations of the traits of the parent species, must be tried under a variety of environments to determine their range of adaptability. Eight hybrids and native pines were planted in 1950 at 5,280 to 6,420 feet elevation in the central Sierra Nevada of California. After 12 years, the most promising hybrid was the backcross Jeffrey x (Jeffrey x Coulter). It showed little damage by insects, snow, or porcupines. This backcross hybrid, now being bred for outplanting on National Forests in California, should be an acceptable substitute for ponderosa and Jeffrey pines up to an elevation of about 6,000 feet.

Prescribed fire effective for aspen conversion. In the Lake States, nearly a third of the forest land is now in aspen. Much of this area might best be converted to conifers if the aspen could be removed and the regrowth of suckers prevented. Studies in Minnesota show that this can be accomplished with two or more prescribed burns annually in the spring before growth begins. An area surprisingly clear of debris and aspen competition can be developed after two or three successive spring burns. This information has practical significance because suitable prescribed burning weather can be depended on in the early spring in the Lake States. Of the brush and hardwood species studied, aspen is the only one that shows decline in vigor and abundance of sprouting after repeated dormant season burning.

Urea form of nitrogen found best for loblolly pine. Loblolly pines, and probably most pines, are selective in the form of nitrogen fertilizer they utilize. In a greenhouse study equal amounts of nitrogen in the form of nitrate, ammonium, or urea were supplied to loblolly pine seedlings. After four months, seedlings supplied with urea had grown the most and had the highest content of nitrogen in the foliage. These results, if confirmed by field trials are of great practical importance because urea is usually the least expensive form of nitrogen fertilizer.

Forest soil and water research findings are being used in the management programs of the National Forests. On the Lake Creek watershed in the headwaters of the Arkansas River in Colorado deep snowdrifts, which will melt slowly to prolong critical late-season streamflow, are being created on massive wind-swept alpine snow fields. Thirteen miles of galvanized steel snow fences, 12 feet high located along the Continental Divide in the high Rockies, have been built, based on alpine snow research results. Clearcutting timber in blocks and strips is also being applied to improve water yield from lower reaches of the drainage. In the California region, research derived principles of rehabilitation for burned areas were applied to the disastrous Coyote fire which destroyed vegetation on 63,000 acres of critical watershed near Santa Barbara in the summer of 1964. Restoration measures included general reseeding for soil stabilization, and permanent conversion of moist sites to perennial grasses for water yield improvement and better accessibility. Debris basins were provided for maximum protection to valuable downstream improvements. All rehabilitation measures were completed ahead of the winter storm season, and no damaging flood flows or soil losses occurred.

Chamise chaparral and other brush successfully converted to grass. A combination of prescribed burning, seeding to suitable annual and perennial grasses and spraying brush sprouts with chemical herbicides has been developed by the Pacific Southwest Station for converting chamis chaparral and certain other brush types to grass. These methods have been extensively pilot tested and are being used in California by National Forest Administration and others in improving brushland livestock range and in clearing areas for fire control.

Results have been put to immediate use through training sessions, movies, annual reports and published articles. Research has been summarized and will be released as a USDA publication entitled "Conversion of Chaparral to Grass in California."

Applications of recreation research results. A system developed by the Pacific Northwest Station for using unmanned registration stations to measure Wilderness use--number of visits, length of stay, use of horses, pressure points, and types of activities such as hunting, fishing, solitude--has been put into effect in all Wilderness and Primitive Areas in Oregon and Washington.

Research results related to the problems and opportunities for income-producing recreation enterprises on privately owned woodlands are in great demand. A paper on the subject presented in Dallas has resulted in many requests for 1 copy, 20 copies, and as high as 1,200 copies. As of July 1, nearly 5,000 copies have been distributed.

The results of recreation research in the Boundary Waters Canoe Area were most helpful to the Secretary's review committee and provided guidelines for the decision of zoning for boat motor sizes, including a zone with no motors.

Infrared fire mapping becomes operational. After three years of research and development aerial infrared mapping of forest fires is being used as an operational measure. The equipment can operate at night or through dense smoke to record the location of the fire edge, pick out hazardous "hot spots" and provide intelligence on adjacent fuel and terrain. As a result fire control action can be planned faster and more precisely. Aerial surveillance removes the necessity for the extremely dangerous job of ground scouting ahead of fast running forest fires.

Chemical and biological control effective against hemlock looper. Studies of the biological enemies of the hemlock looper have revealed that chemical control may be applied with no injury to the primary parasites. Of the seven insect species found parasitic on the looper, the two primary parasites attack the pest when it is in the late larval stage. During outbreaks when control is needed, chemical treatment is made against the young early stage loopers at the time parasites are inactive. Thus, there is no killing of the parasites. They are maintained in the environment to later parasitize loopers which might have escaped the spray and to delay the development of outbreaks in years following the spray treatment.

Virus disease causes decline of outbreaks of Douglas-fir tussock moth. Research on the nuclear polyhedral virus disease of the tussock moth in the Northwest indicates that the disease plays an important role in the termination of outbreaks of the pest. The virus was isolated from diseased larvae found in the forest. Studies showed that the disease kills a large proportion of the very young tussock moth larvae. A second wave of mortality affects later larval stages. In outbreaks in the State of Washington few larvae reached maturity. The polyhedral disease of the very young larvae appears to be caused by surface contamination of the eggs. Research is in progress to determine the biology and behavior of the virus and how and when it should be applied to tussock moth infestations to achieve best control.

Sex attractants isolated from pine bark beetle. A breakthrough in research on the highly destructive pine bark beetles has been made by scientists of the Stanford Research Institute under a recently executed grant. Two chemical compounds that are active sex attractant ingredients of male Ips confuses have been isolated and identified. The discovery will utlimately lead to a better understanding of bark beetles, their behavior and the factors leading to outbreaks. The principles and techniques developed in this research will undoubtedly lead to discovery of attractant compounds from other pine bark beetles and perhaps other insects.

New, safe, non-persistent insecticides show promise against defoliating insects. Promising results in the evaluation and development of safe, non-persistent insecticides are being obtained at the recently established chemical screening project at Berkeley, California. Preliminary evaluation of 24 different materials for control of destructive leaf-feeding insects has been completed. Several chemical formulations gave higher contact toxicity than insecticides used against these insects in the past. They are non-persistent with characteristics which should allow their use with little or no effect on other organisms in the environment. A stabilized pyrethrin formulation has proven particularly successful in the laboratory; it will soon undergo field testing. The new compounds are presently being tested against the Douglas-fir tussock moth, the spruce budworm and the pandora moth.

Long-term population studies indicate better control techniques against gypsy moth. Analysis of a 21-year record of gypsy moth abundance in Massachusetts, Maine, and New Hampshire and a 6-year record for New York is providing the basis for evaluation of infestations and proper selection and timing of control techniques. Life table data, dissected and analyzed through a series of mathematical models, revealed these facts: Variation in adult sex ratio is an important determinant of population trend from year to year; the sex ratio was determined largely by disease affecting large male and female larvae and disease and parasites affecting pupae. Incidence of disease and parasites was in turn determined by the

population density of the gypsy moth; they were negligible when moth population was low. Thus control of heavy moth outbreaks may best be attained by environmental manipulation to encourage disease or by introducing a supplementary disease organism. Outbreaks may be kept at low levels by maintaining conditions in favor of parasites and predators (including birds and small mammals) or through the use of sterilized or otherwise genetically altered male gypsy moths.

Identity of pine canker fungus determined. Red and jack pines in the Lake States have been subject to cankering from an unknown cause for several years. A fungus has been isolated and found to be new to North America. This pathogen is serious on spruce and pine in western Europe and in recent years has been particularly severe in Scotch pine in nurseries. In this country the potential threat is still unknown. The danger will be increased if the fungus is found to attack our native spruce and pines other than these species now known to be susceptible. Now that the canker is known to be fungus-caused it should be easier to determine its occurrence and to prevent its spread to new locations.

Induced mutation of western white pine. An effective method of inducing genetic mutations in western white pine may prove invaluable in developing strains resistant to white pine blister rust. Disease researchers have found that the chemical mutagen ethyl methane sulfonate when applied after stratification of western white pine seed, significantly alters time of germination, percentage of germination and time of primary leaf development. Differences in coloration and size of secondary foliage have been recorded. With such evident changes in morphology and phenology the possibility of altering genetic resistance is definitely enhanced. To test for resistance to the rust fungus, mutated seedlings will be subjected to rust infection through artificial inoculations under optimum conditions.

New log grades for Douglas-fir. A new three-grade system for grading inland Douglas-fir logs in standing trees was developed. It has been adopted for standard usage by the Forest Service in the 11 Western States and replaces at least two systems now being used. The new grading system has fewer grades, is easier to learn and apply, and segregates logs into value classes more accurately than do existing systems. After lumber yield tables are developed for the new log grades by the respective Regions, usage is expected by other Federal agencies and by industry.

New data on properties of western woods. Research to improve the base for the design stresses for nine high priority western woods has been completed and the results made available to industry. This is a milestone in a major study, initiated in 1960, that involved the systematic sampling of all commercially important softwoods from the Great Plains west to the Pacific Ocean. The research established, for Douglas-fir, white fir, California red fir, grand fir, Pacific silver fir, noble fir, western hemlock, western larch, and black cottonwood, new values for average specific gravity by several difference area breakdowns, data on the variation within species, and a comprehensive analysis of the major environmental and other factors that affect specific gravity. Also the research filled gaps in existing data on specific gravity-strength relationships for these species. The research provided western wood industries with a procedure that will insure most efficient marketing, and sets up a basis for establishing basic and working stress values that are not subject to question or misinterpretation. Application of results will also assist forest managers in growing higher valued trees for the future and will help forest geneticists locate trees of superior quality which can be used for breeding stock.

Animal feed from stream pollutant. Research in wood chemistry assisted a major hardboard manufacturer in the production and marketing of a byproduct carbohydrate concentrate. This application of research made possible the conversion of stream polluting waste pulping liquors to wood molasses (solubilized wood carbohydrate) for animal feed and for industrial uses. This operation improves the company's raw material utilization and can add the better part of a million dollars to revenues.

New tires permit logging road cost reductions. Results of a recently completed study on the effect on roads of the new wide single tread truck tires point the way to savings of between $750 and $1,000 per mile in construction of ballasted type logging roads where full scale use of the new tires can be planned. Since many thousands of miles of such roads are built annually (2,000 miles in one Region alone) the potential savings can be significant.

National report appraises timber trends in the United States. A new appraisal of the timber situation and outlook in the United States indicates that future supplies of timber will be adequate to meet projected demands for the next two or three decades, but not in later years of this century unless forest management and utilization are improved. Inventories of timber are now increasing as a result of recent forestry progress, but a continuing decline in the quality of available timber resources is of serious and growing importance. The problem of quality is of particular concern to industries such as lumber and plywood which require larger sizes of preferred species. For the pulp and paper industry, on the other hand, the timber supply outlook is relatively favorable. Foreseeable timber

demands at the end of this century could be met by further improvements in technology to increase the efficiency of processing and marketing timber products, and by increased efforts to expand usable supplies of timber. Such measures as timber stand improvement and planting, particularly on farm and miscellaneous private ownerships, are of particular importance in achieving a continuing balance of timber supplies and demands in future decades.

Thinnings profitable in young-growth Douglas-fir stands. Commercial thinnings in young stands in the Douglas-fir region in Washington have provided annual cash incomes and at the same time have increased the rate of earnings on the remaining growing stock. Extension of thinning practices to the millions of acres of young-growth forests in this region represents a major opportunity for increasing allowable cut and for maintaining established timber industries.

Timber resources provide opportunities for new industries in rural areas. Studies in selected areas of West Virginia and the northern Lake States have provided information on the relative importance of different production factors such as available timber supplies, water, labor, and transportation in determining opportunities for expansion of local industries and employment. Such evaluations of available resources are of key importance in guiding programs for rural areas development.

I. TIMBER MANAGEMENT RESEARCH

A. SILVICULTURE

Problem

The broad field of silviculture includes the problems of growing and tending forest trees and stands from seedlings to sawtimber. It deals with reproducing forests both naturally and artificially, with intensive cultural measures for improving the yield and quality of forest stands, with methods for evaluating and improving the productive capacity of forest soils, and with cutting methods required to perpetuate valuable species adapted to the site. Related to all of these problems are the basic physiological processes involved in tree growth.

Evaluation of soils and sites for the establishment, growth, and development of various tree species is basic to intelligent forest management. Knowledge of proper species or mixtures best adapted to particular sites is needed to guide regeneration programs, timber stand improvement operations, and stand conversion. The integration of fundamental and developmental research into systems for managing forest properties is the final phase of silvicultural research. Forest managers need to know how various prescriptions for better forest practices fit together into a unified management program. They also need to know how best to modify silvicultural practices to accommodate other forest uses such as watershed, range, and wildlife management and recreation on areas managed for timber production.

USDA and Cooperative Programs

A continuing program of research at all 10 Forest Experiment Stations and the Institute of Tropical Forestry in cooperation with various schools, State forestry groups, private industries, and other private forest landowners is conducted in this field of silviculture. Included is a comprehensive program of basic and applied research in seed production and seed handling, forest nursery practice, site preparation, direct seeding, and planting techniques for important timber species. Also included at specialized laboratories are studies on the uptake of systemic chemicals, the physiology of wood formation, the control of growth and dormancy, role of mycorrhizae, mineral nutrition of trees, breakdown of litter into humus, physiological control of flowering and fruiting, and soil characteristics in relation to growth. Studies of natural regeneration and of the care and improvement of existing forests through pruning, thinning, weeding, and other stand improvement measures are carried on in all Experiment Stations.

A long-term program of research comparing different silvicultural systems in different forest types and stand conditions is conducted at many of the Stations to provide operational answers for forest managers. Such studies often are conducted in cooperation with timber companies who may provide forest lands or purchase timber under contracts requiring species treatments and records.

The total Federal effort in silvicultural research in the United States amounts to about 200 man-years annually.

A program of research is also carried on under Public Law 480 in Finland, Greece, Israel, Italy, Poland, Spain, India, and Brazil.

Progress -- USDA and Cooperative Programs

1. Site Evaluation and Soil Improvement

In order to find out where high-value timber will grow best, silviculturists have been determining the site requirements for a variety of southern hardwood species. Some of the most important factors are various attributes of the soil. For willow oak in the mid-South, the best sites are found on soils that are well-drained, low in clay content, with 20 to 30 inches of soil above a clay or hard-pan layer. On such sites, willow oak will grow to a height of 100 feet in 50 years.

In another approach to delineating sites for growth of desirable southern hardwoods, the principal soil series in the mid-South were rated for the potential growth. With the aid of a soils map or by local soil surveys, the forest manager can determine which hardwood species to favor on various parts of his timberland.

For some purposes, an adequate estimate of the potential of the site for growing oaks can be made from measurements obtained from topographic maps or aerial photographs. In a study in West Virginia on soils derived from sandstone and shale, site index of oak was found to be strongly related to the aspect to the position relative to the top of the slope, and to the percent of slope. A predicting equation based on these three variables explained 74 percent of the variation in site index. Forest managers in this area can easily predict the best sites on which to grow oak. This predicting equation on soils derived from limestone, however, was found to be not as accurate. On these soils the site index was generally higher than on other soils for the same topographic conditions.

Looking toward future needs for more intensive silviculture, a study in Arkansas showed that fertilization and irrigation increased the yield of pulpwood in a loblolly pine plantation by 34 percent. For an 8-year period the plantation grew at the rate of 2-1/2 cords per acre per year. Although the specific gravity of the wood decreased following fertilization alone, the combined watering and fertilizing treatment resulted in only a minor decrease in specific gravity. The yield of pulpwood on a weight basis thus increased substantially.

Analyses of the mineral nutrient content of the leaves of forest trees have been used extensively to diagnose fertilizer requirements and site productivity. New research in the Northeast shows that the nutrient relationships to growth can be very complex because different phases of growth may be affected in different ways by the availability of different nutrients. On sandy loams derived from micaceous schists in western Massachusetts, it was found that height growth in red pine is related to calcium uptake, basal area growth to potassium uptake, and volume growth to soil moisture storage of the soil. These different growth responses may be due to seasonal changes in the availability of individual nutrients and of soil moisture, which in turn may affect the growth processes that predominate in different seasons. This research indicates that diagnosis of nutrient needs from foliage analyses requires a more thorough understanding of the factors that control different phases of tree growth.

2. Artificial Regeneration (Seeding and Planting)

a. Seed production and handling

Proper handling of forest tree seed from the time of collection until they are planted is becoming more important with the increased emphasis on seeding and planting as means of regenerating the forests. A cone collection study in western Oregon revealed that germination of noble fir seed improved as cone collection time approached the time of natural seed fall. However, seed obtained from cones collected 6 weeks before natural seed fall and allowed to after-ripen in the cones germinated about three-fourths as well as seed from later collections. This means that when necessary, the noble fir cone collecting job can be started up to 6 weeks before natural seed fall without losing more than 25 percent viability.

The care exercised in cone collection and seed handling can affect the size and quality of seedlings. Although it had been known that careless handling could cause large losses of seed, a study of sugar pine in California revealed that size of the seedlings could also be affected. Seedlings from cones picked at the proper stage of ripeness and promptly dried were appreciably larger than those from cones collected without special care. Improvement in seed handling methods could lead to a reduction in the proportion of cull seedlings and could facilitate a shift to 1-0 seedlings instead of the more expensive 2-0 seedlings.

Most artificial regeneration programs require that seed be collected during good seed years and stored so they will retain their viability and be available for use during poor seed years. Recent studies have shown that longleaf pine seed can be stored under favorable conditions for at least 7 years without loss of viability. Seed with 8 percent moisture stored at 0°F., 25°F., and 34°F. had a germination of 84, 80, and 75 percent, respectively. Seed with 14 percent moisture

stored at the same temperature had a germination of 80, 50, and 12 percent, respectively. Field trials have borne out the conclusion that low moisture content of seed and low storage temperatures were best for retaining viability of longleaf pine seed. This research will help reduce waste of stored seed attributable to unsuitable storage conditions.

The effectiveness of stratification in breaking dormancy of loblolly pine seed can be more than doubled by exposing seed to light during stratification. Germination increased directly with the length of stratification periods ranging from 7 to 56 days. It increased from 8 to 57 percent for dark-stratified seed and from 52 to 98 percent for light-stratified seed. In addition to increasing the amount of germination, light during stratification reduced the time required for germination by about one-half. This new information will be of special value when seed supply is low and when time for stratification is limited. It will be of particular value in getting maximum germination of high-value seed from improved and superior trees.

b. Seeding and planting

Direct seeding is a promising method for converting low-grade hardwoods to more profitable eastern white pine on the Cumberland Plateau of Tennessee. Stratified seed were sown on seedbeds prepared by light disking. A low grade oak-hickory overstory was deadened in May after the April seeding. Four growing seasons later, plots sown with repellent-treated seed had 2,050 seedlings per acre, with 78 percent of the milacres stocked with one or more seedlings. Similar studies of direct seeding loblolly, shortleaf, and Virginia pine in the Western Highland Rim of Tennessee gave even better results. Three years after seeding on disked seedbeds there were 3,900 loblolly, 2,600 shortleaf, or 2,200 Virginia pines per acre. The five main requirements for success in direct seeding pines here are: (1) break up hardwood litter, (2) use a repellent, (3) seed in winter or early spring, (4) stratify seed for late sowing, and (5) deaden competing vegetation.

The possibilities of direct seeding in New England have not been fully explored. A direct-seeding study in southeastern Maine revealed that seedbed preparation, shading, season of sowing, year, and soil type had appreciable effects on seed germination and first-year establishment of some or all species. Germination and establishment of white spruce and pitch, red, and white pine were consistently best on scalped, shaded plots. In general, seedbed preparation and shading were more beneficial on an excessively-drained loamy sand than on a sandy loam. These results point to the fact that the requirements for successful direct seeding must be developed and prescribed for different species, climates, and soils.

Treatments designed to give better early survival of pines have an added advantage of promoting greater growth. In east Texas, those treatments, such as scalping and mulching, which reduced weeds brought about the highest survival of loblolly pine. In addition, trees on these scalped and mulched plots averaged 20 feet in height after 5 years, compared to only 17 feet on untreated plots. Another study in Georgia showed that benefits of site preparation are due more to faster growth, which results in greater total wood production, rather than to the greater number of trees resulting from increased survival.

In northern Florida, characterized by very long growing seasons and wet summers, recent research showed that slash pine can be planted successfully as early as mid-July of the year in which seed is sown in the nursery. The summer planted stock survived and grew as well as did winter planted 1-0 stock. Summer planting in the sub-tropical climate of north Florida has several advantages: (1) a longer planting period and less chance of seedling losses when weather or other conditions prevent planting in the usual season; (2) nursery work can be spread over a longer period and thus avoid the seasonal rush; (3) use of nursery and planting equipment will be spread over a longer period; (4) manpower for summer planting can be utilized, in some cases, during what might otherwise be a slack season.

Extensive experimental plantings in eastern Tennessee have shown that abandoned, eroding old corn and tobacco fields occupied by weeds, broomsedge, and blackberries can be replanted satisfactorily if the proper species are used. Of the 14 species studied, shortleaf pine, white pine, and yellow-poplar had the best survival and growth rate, and were the only species that produced a merchantable crop in 20 years. Shortleaf pine grew well on limestone-derived soils, shaly soils, and cherty dolomite soils, and on north and south slopes. White pine grew better on north than south slopes. Yellow-poplar grew twice as fast on limestone and shale soils as on dolomite soils, and much faster on north than on south slopes. In general, pines should be planted on these abandoned fields except yellow-poplar may be planted on better soils on north slopes not damaged by erosion.

Concern over the possible effects of malformed root systems of planted trees led to a long-time study in New Jersey to compare the development of root systems of seeded and planted loblolly, pitch, and shortleaf pines. Natural seedlings had well-developed tap roots with right-angle lateral roots on all sides. Seedlings planted in shallow slits had the expected J- or L-shaped tap roots with a cluster of intertwined lateral roots mostly in one plane. Careful planting in deep slits reduced the number of trees with misshapen tap roots but not the number of trees with roots in one plane. At the end of 2 years, the abnormal root systems had penetrated as deep as others and had no evidence of root rot. The main value of this study will come later when information becomes available on root firmness, susceptibility to decay, and growth rate at different

stages of tree development to maturity. In the meantime, when planting is necessary to regenerate new stands, 1-0 seedlings should be planted as carefully as economic considerations will permit.

3. Natural Regeneration

Continued progress is being made in finding ways to improve natural establishment of desired species in some of the areas where regeneration after cutting is a problem. Careful handling and scattering of logging slash bearing serotinous (closed) cones usually provides adequate natural regeneration of lodgepole pine in the Northern Rocky Mountains except in southwestern Montana and eastern Idaho. Here, late germination of seed and summer droughts are the main causes of failure. Recent studies have shown that complete site preparation, aimed at conserving soil moisture, will result in satisfactory regeneration with a seed supply of 30,000 to 50,000 viable seed per acre. This information used in connection with a newly developed technique for estimating the amount of seed in serotinous cones will make it possible to schedule harvest cuttings and ground preparation to improve natural regeneration of lodgepole pine in these problem areas.

Detailed studies of the reproductive habits of yellow-poplar are providing reliable methods for regenerating this valuable species after clearcutting. In a recent study in Illinois and Indiana, it was found that yellow-poplar seed remained viable for at least four winters in the forest litter. Under natural conditions viable seed accumulate for several years and germinate when seedbed conditions are suitable. Some seed germinate in the forest litter before harvest cutting, but the seedlings rarely live more than one growing season. Natural stratification on the forest floor for one winter does not break dormancy in all seed, but after stratification for two winters most of the seed will germinate if other conditions are favorable. With proper harvest cutting to expose a favorable seedbed there is little need to reserve seed trees on harvested areas to reproduce yellow-poplar.

Shortleaf pine is an excellent timber tree for the Piedmont region of the Southeast, but getting a new crop after harvest is a major problem for forest managers Systematic research on the reproductive habits of shortleaf pine, designed to solve this problem, included a 10-year record of the annual variation of seed crops in different parts of the Piedmont. Annual seed fall varied from practically no seed to over a million sound seed per acre. Good crops (over 100,000 sound seed) occurred 40 to 50 percent of the time in the Southern Piedmont, but seed crops were less frequent and much less abundant further north to Virginia. Individual stands differed in size and timing of seed crops, but good seed crops occurred throughout most of the area in 3 years out of the 10. The influence of weather on seed crops was difficult to evaluate, but one complete seed failure throughout the Piedmont was attributed to a severe frost. Further studies of the chain of events which control success or failure of the new tree crop are underway

Recent research in Alabama has improved prospects for successful natural regeneration of longleaf pine, the prime poletimber species of the South. Maximum per-acre seed production was reached under overstories with densities of 35 to 50 square feet of basal area per acre. Under overstories ranging up to 90 square feet of basal area unburned longleaf seedlings survived as well as those with no tree competition. After 7 years, milacre stocking averaged 99 percent and survival 72 percent. Brownspot disease built up slowly and stabilized at low levels in forest stands, but it spread and intensified rapidly in nearby open areas. Seedlings responded promptly to release, even when suppressed as long as 8 years. This means that longleaf pine may be regenerated in advance under heavy overstories and then released for increased growth.

Stands of pole-sized sweetgum trees in Mississippi can be perpetuated by coppice regeneration. On clearcut areas 65 to 80 percent of the stumps of all sizes up to 18 inches in diameter produced root and stump sprouts, resulting in a new stand of 800 to 900 stems per acre. When 6 years old, the sprouts averaged 16 to 22 feet in height and 1.5 to 2.3 inches in diameter. This method of regeneration has two distinct advantages: (1) it reduces costs by eliminating the need for seed and for site preparation, and (2) the fast initial growth enables the sprouts to overtop the myriad of vines, briars, and other less desirable vegetation that usually invade the new openings in hardwood stands. Coppice rather than seedling regeneration is especially suited to management of sweetgum stands for pulpwood production.

4. Silvicultural Systems

Research continues in all sections of the country to develop methods for growing stands of the species and quality needed to satisfy the many requirements of multiple-use forestry.

Wind damage is a serious problem in several forest types. Over 99 percent of the loblolly pines injured by Hurricane Donna in eastern Virginia and North Carolina had damaged root systems rather than broken stems. Damage was more severe on soils having moderately coarse-textured profiles than on those with fine-textured profiles. It was most severe when hardpan or clay layers within the soil restricted root and water penetration.

Timber harvesting frequently renders adjacent stands vulnerable even to normal storms. Old-growth spruce-fir forests in the Rocky Mountains incurs above-average losses along the margin of clearcuts if the stands are in exposed positions, in locations where the wind is accelerated because of topography, on shallow or poorly-drained soils, or where the trees are old, defective, or have been grown in dense stands. After an examination of 234 clearcut areas, a number of recommendations have been made to reduce blowdowns in the Rocky Mountains. The special problem of topographically accelerated winds can best be handled by locating the vulnerable leeward boundary in protected areas, or by progressive strip cutting of lee boundaries into the wind.

A study of non-merchantable trees left after clearcutting in Alaska indicated that only 51 percent of them survived for 5 years. Wind and logging damage caused greatest mortality. Diameter growth after release was good but height growth was poor. It seems unlikely that these residual trees will form a significant part of a new stand or be detrimental to its establishment. They may, in some cases, serve as supplementary seed source on cutover areas. There appears to be no silvicultural reason for eliminating residual trees in this and comparable situations.

At the present time, a relatively large proportion of the sawtimber-sized material cut from the older northern hardwood stands in the Lake States region is not suitable for manufacture into high-value products because of rots, stains, and other defects. Comparison of cull in trees harvested from stands that were cut selectively one, two, and three times during a period of 35 years suggests that much of this cull material is a result of over-maturity or simply failure to remove it in earlier cuts. Under proper management, cull does not develop as fast as growth increases. In the future, foresters can expect to have a much smaller amount of cull volume in their managed stands.

Additional evidence of the profitableness of managing forest property in the Eastern United States is available. For example, 10 years of intensive management of a slash-longleaf forest in the middle coastal plain of Georgia raised the level of stocking from 1,130 board feet per acre to 2,300, even after 1,136 board feet per acre had been harvested. Management costs averaged $1.15 per acre annually. A net return of $5.88 per acre, including the increased value of the growing stock, was realized. As a result of good fire protection, slash pine is becoming the dominant species on the forest.

At the Crossett Experimental Forest in Arkansas, the "Good" and "Poor" Farm Forestry Forties have been under continuous and intensive management for 27 years.

Work on the Forties has shown that understocked stands can, in a very few years, be built up to good stocking and attain a high growth rate. There must be a reasonable number of good stems per acre to work with, some trees of the seed-producing size must remain, competing low-quality hardwoods must be controlled, and the area protected from fire. Stocking on the "Poor" Forty was built up to desirable levels in 13 years. Over the last 10 years gross value of forest products cut from the "Good" Forty has averaged $16.71 per acre; from the "Poor" area, $13.26.

5. Stand Improvement

a. Prescribed burning

Prescribed burning of ponderosa pine has been suggested as an inexpensive method for thinning dense sapling stands. Six years after a prescribed burn in young ponderosa pine stands in north-central Washington, height growth of crop trees was reduced. However, diameter growth was not different from that of an unburned area. Prescribed burning definitely removed sub-dominant trees. This study showed that prescribed burning is a rough and largely unpredictable tool for thinning.

In the Lake States, nearly a third of the forest land is now in aspen. Much of this area might best be converted to conifers if the aspen could be removed and the regrowth of suckers prevented. Studies in Minnesota show that this can be accomplished with two or more prescribed burns in the spring before growth begins. An area surprisingly clear of debris and aspen competition can be developed after two or three burns in the spring, which is the only season that offers dependable prescribed burning weather in the Lake States. Of the brush and hardwood species studied, aspen is the only one that shows a decline in vigor and abundance of sprouting after repeated dormant season burning.

Hazel brush, because of its shading and aggressive growth, is a major deterrent to establishment and growth of conifers in the Lake States. Cooperative studies showed that single or repeated spring fires easily kill aerial stems of hazel. However, prolific resprouting follows each fire. Single and repeated summer fires also kill aerial stems, but resprouting is progressively less vigorous after each fire. Single summer fires which completely consume humus are possible only after long drought, but they can eliminate shallow-rooted hazel. Single or repeated hot fires in summer or fall primise to give the best removal of hazel brush.

Shortleaf pine is a better commercial species than most native hardwoods for the dry uplands in Kentucky. However, hardwood sprouts are fast-growing and shade the intolerant pine seedlings. In order to obtain natural pine regeneration, some practical method must be found to destroy the dense hardwood understory or at least retard its growth. Fire has been successfully used to control hardwood understories in the Piedmont and Coastal Plain, but controlled burning during the dormant season, the only time of year feasible to apply it on the Cumberland Plateau, failed to control the understory. Although the height of the understory was reduced, the number of hardwood stems increased greatly after each burn. Thus, burning during the dormant season should be avoided as it accentuates the hardwood problem rather than alleviating it.

b. Herbicidal control of unwanted plants

Herbicides are needed to kill woody brush that retards growth of natural conifer reproduction in California. Eight-year-old sugar pine reproduction within clumps of mountain whitethorn increased height growth for 2 years after foliar applications of herbicides. Aqueous sprays of the low-volatile esters of 2, 4, 5-T were more effective than comparable 2, 4-D treatments. The season and rate of application strongly influenced the results. Sugar pine survival and growth were good and brush kill was high when one pound acid equivalent per acre was applied in September. Silviculturists now have a cheap, effective means of releasing sugar pine reproduction.

Many landowners in Louisiana have been reluctant to invest in hardwood control by tree injection until seedling establishment is certain. Studies near Alexandria, Louisiana show that growth of loblolly pine seedlings is substantially retarded when release is deferred for a year or more after seeding. Regardless of site or cover conditions, delay until the end of the critical first growing season results in growth reduction, and stocking may be seriously depleted. Seedling failures rarely occur on an average or better site when hardwoods are deadened promptly. The results show that hardwood control costs will be returned through increased growth and stocking. Prescriptions have been developed for the most effective dosage of lower cost, 2, 4-D amine and wider spacing of injector incisions to kill hardwoods of different sizes and species at various seasons of the year. Costs are estimated to be reduced from $4.32 to $1.84 per acre by the use of the cheaper chemical, and by application in the growing season when fewer incisions and a lower dosage are possible.

Managers of northern hardwood stands need to know the costs and effectiveness of applying chemicals in frills to kill unwanted northern trees. Recent studies show that a 40-percent solution of sodium arsenite in complete frills produced nearly a 100-percent kill in a 2-year period. Partial frills were nearly as effective. Next in effectiveness was a mixture of 2, 4-D and 2, 4, 5-T in oil, single or double applications of which produced about an 82-percent kill. Treatments using 2, 4, 5-T and machine girdling were the least promising. These results provide a basis for planning commercial TSI operations in northern hardwood stands. Also, in the Northeast, studies show that a mixture of Tordon 22 K and Tordon 101 (forms of picolinic acid), has superior translocation properties over the commonly used 2, 4-D and 2, 4, 5-T. The Tordon mix is effective when as little as 1 ml. is injected at 6-inch spacings on oak. Season appears to have no effect on results. Other studies show that injections of water soluble amines of 2, 4, 5-T are twice as effective during the peak of the growing season as at other seasons of the year.

6. Animal Damage

Knowledge of the populations of animals which cause damage and of their habits is essential in working out control systems or in learning how to live with the animals.

In the loblolly-shortleaf pine forests in Louisiana, the rodent population varied from 0.1 to 4.0 per acre. The greatest numbers of rodents occurred where understory vegetation was the densest. The species of rodents varied according to the vegetation; some were more common in brushy areas, others in grassy areas. Disturbance, such as fire, usually changed the species composition but not the total population. Such information will be used to guide future rodent control programs.

In a cooperative study, zoologists of the University of California found that fungi and tree seed were the principal items of the diet of the pine squirrel. These squirrels cut numbers of cones during the fall and store them for food. During a 5-year study, tree seed made up 36 percent of the food of the squirrels, but fungi made up 56 percent. The balance of the diet consisted of insects, twigs, leaves, etc. Tree seed was an important part of the diet during 5 months of the year. Cutting of the cones for food severely restricts natural regeneration in years of small seed crops. Any program for control of the squirrels would have to consider the seasonal diet of the squirrels.

Preventing the loss of seed to predators is a problem in both artificial seeding and natural regeneration. In a study in southwest Alabama, predators destroyed 93 to 99 percent of unprotected longleaf pine seed and seedlings within 3 months following seeding in November. Small mammals, mostly mice, accounted for 58 percent of the losses during a 3-year period. Birds and large mammals were next with 33 percent. Insects, mostly tropical fire ants, accounted for 9 percent of the loss. Most losses occurred within 6 weeks after seed were exposed. Losses to small mammals started out high and dropped sharply as seed started to germinate. Ants did most of their damage after the seed started to germinate. Damage by large mammals fluctuated but continued until about the time the seed coats were shed. Losses to predators virtually ended with the emergence of primary needles. This information on the time of greatest activity of the different types of predators will be useful in scheduling control measures. It also emphasizes the importance of quick germination and fast, early growth of seedlings in reducing losses to predators.

Light burning increased the amount of longleaf pine seed lost to rodents compared to that lost on unburned areas. Most of the seed exposed in the burned area was taken within a week and all was taken in a period of 2 months. Mice of various species were the most common rodent caught in the burned and unburned plots. Burning to prepare a seedbed in advance of direct seeding or natural seeding increased losses to rodents if some form of rodent protection is not applied.

A minimum dosage of TMTD to deter rabbits from planted seedlings has been worked out. This chemical (tetramethylthiuramdisulphide) has been shown to repel rabbits in cage-trials but was not consistently effective in operational planting. A detailed study showed that the treated seedlings had far too little of the chemical to deter the rabbits because of the method of application, quality of the adhesive, and

weathering losses. On the basis of the amount needed to repel the rabbits, 11 to 22 milligrams of chemical per tree would have to be applied in the nursery in order to be effective after planting. It also showed that a more effective "sticker" substance is needed in applying TMTD.

Compound 1080, a very hazardous poison, is of limited use in treating tree seed as protection against rodents. In a cooperative study, zoologists of the University of California fed common forest rodents pine seed which had been treated with different amounts of 1080. They found that the rodents did not develop a bait shyness but were able to detect very small amounts of poison on the seed. The rodents could discriminate between treated and untreated seed if they had previously received a sub-lethal dose. They would accept either treated or untreated seed on the first presentation. In order to be effective, each treated seed would have to carry a lethal dose of poison. Such a dosage reduces the viability of the seed and all seed would have to be treated. Because of the nature of the chemical, this procedure might be too hazardous.

7. Growth Requirements

A forest is one of the more efficient forms of vegetative cover for converting light energy to plant materials. Its photosynthetic efficiency is often higher than that of agricultural crops. In a review of data available on this subject, three factors that appear significant in explaining this greater efficiency are: (1) the low efficiency of agricultural crops in the early part of the season until the canopy closes, in comparison to forests which usually have complete canopy closure all season, (2) the available forest data are from areas with relatively low light intensity, which tends to increase the efficiency of light utilization, (3) carbon dioxide becomes limiting for photosynthesis in stands of plants under full sunlight, but because of the physical structure of the plant communities, forest stands possibly have more carbon dioxide available to them than do agricultural crops. This analysis gives added insight into the factors controlling forest production and its theoretical potentialities.

One of the reasons for the high photosynthetic efficiency of coniferous forests is that some are active the year around. A cooperative study between the Forest Service and the University of Washington showed that the seasonal net gains of photosynthate in young Douglas-fir stands varied from 20 percent in the winter to 35 percent in autumn during a dry year. In a moister year the relative amounts increased during the summer and decreased in winter. Pruning of lower branches caused an increase in net photosynthate in codominant trees but not in dominant trees. These lower branches may represent a drain on the tree rather than a productive asset. Thinning also brought about an increase in net photosynthate of codominant and other lower crown classes but not in dominant trees.

Year-old needles contribute most of the photosynthate for new diameter growth. A Pioneering Research Unit in tree physiology determined the contribution of needles of different ages to terminal elongation and to increase in diameter growth of red pine seedlings. Reserve food in the plant apparently contributed most to terminal elongation, although developing needles added photosynthate also. These findings add to our increasing knowledge about the physiology of growth and wood formation, and provide a basis for the development of more productive silvicultural practices by showing how growth is controlled.

In longleaf pine also the initial flush of terminal leader elongation results from food reserves. A study in Mississippi showed that the food reserves in the stem accounted for 31 percent of the terminal growth and that in the roots for an additional 15 percent. Photosynthate from the needles on the seedling at the time of stem elongation provided for the rest of the terminal growth. Loss of the old needles from fire or disease thus will reduce height growth by about half.

The amount of soil moisture available to the stand will determine its growth and to a degree the basal area which should be carried for growing stock. In a study in Arkansas, the amount of available soil moisture was related to growth in stands which had been thinned to 55, 80, and 125 square feet of basal area per acre. Growth on the 55-square-foot plots was 89 percent of that on the 125-square-foot plots. On the high-basal-area plots, available water reached a critical level in July and growth practically ceased. On the low-basal-area plots moisture was available through most of the summer season and trees grew until fall. The results point out the need to balance the stand volume being carried with the potential capacity of the site.

Mycorrhizae, which are considered to be essential for good growth of most trees, are not seriously inhibited by either sterilant treatments in the nursery or by slash burning in the forest. In a PL 480 project in Finland, mycorrhizal development was delayed on pine and spruce seedlings after the nursery soil had been treated with various sterilants to control weeds and disease organisms. But by the end of the season the mycorrhizal development and seedling growth equalled, or in some treatments exceeded, that in the untreated soil. Similarly, slash burning retarded but did not prevent mycorrhizal formation. The high surface temperatures did not penetrate deeply enough to kill the fungi and the increase in pH resulting from release of bases was not enough to inhibit fungi. These findings are important in that they remove doubts concerning the deleterious effects of these common silvicultural practices.

Fumigation is normally done in nursery beds to control fungi and other microorganisms. But work recently completed with Monterey pine in California points out that the root-regenerating potential of seedlings from treated beds is greater than from untreated beds, especially for stock lifted in late winter and early spring. Plantations developed from these trees have advantages in survival and growth rates, apparently due to control of the fungi, Pythium spp.

Loblolly pines, and probably most pines, are selective in the form of nitrogen fertilizer utilized. In a greenhouse study equal amounts of nitrogen in the form of nitrate, ammonium, or urea were supplied to loblolly pine seedlings. After 4 months seedlings supplied the urea had grown the most and had the highest content of nitrogen in the foliage. These results, if confirmed by field trials, are of very practical importance because the urea form of nitrogen is usually the cheapest type of nitrogen fertilizer.

Low soil fertility is an important cause of poor quality of desirable hardwoods on abandoned agricultural land in the Central States. Phosphorus commonly is deficient in these soils, according to a nutritional study in Indiana. Even though the physical characteristics of the soils seemed satisfactory, growth of trees was poor if fertilizer containing phosphorus was not added. A complete fertilizer gave best results and that without phosphorus gave poorest. These results help explain why good hardwoods cannot now be grown on abandoned farmland which, at one time, probably supported good hardwoods.

Studies on the nutritional responses of trees, or other plants, require large amounts of very pure distilled water. Failure to meet this need either limits the research or the validity of the results. To provide for distilled water of maximum purity, forest scientists at Beltsville, Maryland, designed a continuous distillation system which yields 8 gallons of water an hour with an impurity of two parts of metal in 10 billion parts of water, or the equivalent of 1 ounce of metal in 5,000 tank cars of water. This water is pure enough for the most sensitive type of nutritional studies and is produced, nearly trouble free, at a very low cost.

Epicormic branching following stand treatment may cause degrade of lumber in some species. To determine the cause of these branches in sweetgum, scientists in Georgia studied the origin of branches, which often develop after a tree is exposed to more light. They found that the buds arose within the basal scales of axillary buds on the terminal shoot. During succeeding years the buds develop even though covered by the bark layer. Knowledge of their origin will be helpful in devising control methods, as by growth regulators. The prevention of the pin knots will raise the value of veneer cut from the trees. In Sitka spruce the development of epicormic branching following opening up of the stand was found to have little effect on the quality of the timber for pulpwood or structural lumber.

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B. FOREST MENSURATION

Problem

Intensive management of the forest types of the United States requires methods of measurement of timber tree volumes and more reliable predictions of future growth, yield, and quality of forest products. Productivity of forests, both in quality and quantity, varies markedly according to stand density, site quality, tree age, and species composition. Optimum stand conditions for particular management objectives need to be determined for the many combinations of timber types, sites, and conditions found in American forests. Important forest regulation problems involving levels of growing stock, cutting budgets, and rotation lengths must be solved to guide wise management of large timber holdings.

USDA and Cooperative Programs

A continuing program of studies is conducted at all the Forest Experiment Stations, often in cooperation with industries, other private landowners, State forestry agencies, and forestry schools. Special attention is being given to research in the growth and yield of managed forests and forest plantations. Research is also concerned with mathematical techniques and forestry measurement tools that will make for greater precision and efficiency in practical forest management operations and in forest research. A Pioneering Research Unit in Berkeley, California, established in 1961, is studying basic mensurational problems. Nationwide, 8 man-years of Federal scientific effort are performed in mensuration research projects, and several additional years are devoted to related growth and yield studies in silviculture projects.

1. Growth and Yield of Forest Trees and Stands

We continue to seek new and more efficient methods to obtain and synthesize growth and yield information. A recently completed Public Law 480 project in Finland proposes a temporary sample plot method for variable density yield tables. The approach is illustrated with data from Scotch pine, but sufficient flexibility is available that the method can be used for species with different growth habits or thinning requirements. The temporary plot approach avoids most of the delays and some of the costs inherent in the permanent sample plot method.

Forest managers need growth information for managed stands of Douglas-fir in the Pacific Northwest. A committee composed of public, educational, and industrial groups has been formed to oversee the installation and maintenance of levels-of-growing-stock studies. Thinning studies are currently repeated six times on site II, III, and IV lands by five different agencies. The growth data developed from this study will later be used for such purposes as determining optimum stocking, maximum financial returns, and desirable rotation ages. The information thus obtained should represent a substantial saving to each of the cooperating agencies.

Overstocking is a serious problem in young stands of western larch. Results of two thinning trials in Montana show that diameter, basal area, and volume growth increased after thinning, but height growth increased only in densely overstocked stands. Growth response was related to stand structure and stocking prior to treatment; that is, moderately overstocked stands responded rapidly and heavily overstocked stands responded slowly. Larch stands should be thinned early from below, before they become heavily overstocked, reserving the more dominant trees with well-developed vigorous crowns.

Overly dense jack pine in the Lake States responded well into precommercial thinning. Twenty-two years after thinning, the 4 x 4 foot spacings had more cubic-foot volume than the 6 x 6 or 8 x 8 foot spacings. Much of the volume on the 4 x 4 spacing, however, was on trees that are likely to die of overcrowding before attaining merchantable sizes. There was no difference in height growth of dominant trees among any of the spacings, nor was there a difference in average stand taper in the first 20 feet of stand height. This latter finding is significant for it has long been suspected that excessive taper on more open stands would cause a loss of merchantable volume in jack pine.

Ten-year measurement records in young plantations of western white pine give added assurance to the present practice of planting to regenerate cutover areas in the Northern Rocky Mountains. Growth rates are superior to comparable natural stands, in part because plantations avoid both the delays of natural regeneration and the early onset of competition from excessive stocking. Two plantations indicate growth rates of 200 cubic feet per acre between ages 20-40, and an average annual diameter increase of almost 0.2 inches per year. Growth rates differ by 50 percent between plantations on fair and excellent sites, pointing out the importance of assigning highest planting priorities to the best sites.

The growth characteristics of tolerant hardwoods have been difficult to study, in part because so many species occur in mixture and in part because we have no good measures of site quality. Research recently completed in the Northeast for even-aged hardwoods developed first a composite site index curve for several species growing in mixture. The study then developed basal area, cubic-foot volume, and diameter relationships from age and the composite site index. Current annual net increment at age 65, for example, ranged from 25 cubic feet per acre per year on site index 50 land to 71 cubic feet on site index 90 land. Of the species studied, diameter growth of white ash was most sensitive to site quality, and yellow birch the least.

2. Forest Measurements

Because so many commercial timber species grow in this country, preparation of volume tables for trees, stands, and forest products continues to be one of the important jobs of measurement research. The Lake States Forest Experiment Station, in cooperation with Region 9, recently prepared a cubic-foot volume table for red

and jack pine poles to aid in what has been a difficult scaling and appraisal problem. Volume tables or volume equations have recently been prepared for lodgepole pine in Colorado and Wyoming; for ponderosa pine in the Black Hills; for white spruce, aspen, paper birch, and cottonwood in Alaska; and for yellow-poplar in the Southern Appalachian region.

The relationship of butt-log quality to d.b.h. has been developed for six Northern Appalachian hardwoods. The log grade-diameter relationships serve both as a first step in research in determining average value-growth rates for measuring economic maturity and as a guide to timber management. Illustrations are given to aid in the very complex but practical problems of timber harvesting in mixed hardwood stands.

A need for the development of site-index information for even-aged hardwoods in the northeast prompted a review of techniques commonly used for construction of site-index curves. New procedures were developed for construction of site-index curves from data obtained by stem analyses of sample trees. These include a method to correct for bias introduced by the tendency to cut stands earlier on good than on poor sites. Compared with the conventional procedures, site-index curves prepared by these techniques are believed to give an improved estimate of the true shape of the growth curve. Provision was made for investigating curve shapes associated with site and species differences.

Stem analysis techniques were used to prepare site-index curves for young growth ponderosa pine in northern Arizona. The curves were checked against field measurements in 75 locations in Arizona and New Mexico. Differences in predicted site index between old and young trees averaged less than 5 feet per location.

In the Central States, useful concepts of stocking have been developed from the growing space required by individual trees. These hardwood stands have rather broad but well-defined limits of stocking within which the growing space is fully utilized and where stand growth is about equal. In contrast to stand growth, however, growth of individual trees is greatly affected. Since quality is so important in hardwoods, the job ahead points to the identification of a narrower range of stocking within which given tree characteristics and specific management objectives can best be achieved.

A better understanding of 3-P (probability proportional to prediction) sampling and a look at its performance were obtained in California by designating and selecting many samples by simulation procedures. A population of 3, 439 trees was recorded on magnetic tape and was sampled 101 times by a computer program which simulated 3-P sampling on a timber sale. It was found that 3-P sampling gave unbiased estimates of the total sale volume. Actual errors were usually well below the error limits specified in the design. The results of this study are significant in that they demonstrate the applicability of a more efficient sampling procedure than was previously available in timber sale appraisal work.

3. Management Planning

As we learn more of the growth responses of timber stands to such environmental factors as age and site, and to such cultural treatments as thinning, release, and initial planting spacing, it is possible to make a better analysis of both the biological and economic options available to the forester to achieve whatever goals he may have for owning or managing the property. The research described below was developed jointly by Timber Management and Forest Economics Research. More of the economic aspects of the work appear in the Forest Economics Research section of this report.

One of the most useful studies in management planning was recently completed for loblolly pine in the Southeast. Comprehensive information on the growth and yield of managed stands of loblolly pine in the Southeast provided the foundation for an economic analysis where profit maximization was to be the goal of management. The analysis provided for varying stumpage prices, stand ages, site indexes, stocking levels, rate of interest and regeneration costs for either pulpwood or sawtimber. A quality differential, expressed in stumpage prices, was recognized.

Stocking levels in loblolly pine which maximize profit are less than those which maximize volume production. Rotation ages are lengthened for lower rates of interest, for better sites, and for higher regeneration costs. Optimum rotation ages for specified interest rates and site qualities varied from 25 to 35 years for pulpwood only, from 35 to 55 years for sawtimber with no quality differential, and from 40 to 70+ years with a quality differential.

Thirteen years of light, frequent thinning in site II stands now 55 and 70 years old, in western Washington, have demonstrated silvicultural feasibility and economic superiority of thinning over no thinning chiefly because of salvage of mortality. An economic analysis indicated that thinning the younger stand should be continued. Under a 3.5 percent after-tax return standard, the older stand is financially mature and ready for regeneration unless a stumpage price increase is anticipated. The unthinned stand fell below 3.5 percent, indicating attainment of economic maturity prior to age 70.

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

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C. FOREST GENETICS

Problem

Extensive and expanding artificial reforestation programs on public and private forest lands create the opportunity for planting genetically-improved trees. Genetics and breeding research programs are under considerable pressure to produce improved strains of trees having faster growth, straighter stems, more desirable wood, superior pest resistance or other desired traits. Basic and applied research are needed to understand the inherent variation in forest trees, to select trees that are inherently superior, and to combine desirable traits into improved strains through breeding.

USDA and Cooperative Programs

This is a continuing, long-term program of tree breeding. It involves basic studies of genetics, breeding, and plant physiology. Research findings are applied to develop improved strains of forest trees. Improvement goals include faster growth, better tree form, high-quality wood, and increased resistance to pests, drought, and cold. Superior trees are selected and bred, and their progenies are evaluated to determine the genetic worth of the selected parents. Outstanding trees are propagated in orchards to produce improved seed. Hybridization is attempted between varieties and species. Any hybrids produced are evaluated, and desirable ones are produced in quantity. Ionizing radiations are used to create new forms of variation. Desirable mutations will be incorporated into useful new tree varieties. Physiological studies facilitate tree breeding by developing methods of vegetative propagation, methods to overcome genetic incompatibility, and methods to assure early and abundant seed production. Other studies seek to explain the physiological mechanisms involved in desired traits like faster growth and resistance to cold, drought, and pests. Research on the identification, classification, and distribution of species and hybrids of forest trees also is included.

The program is carried on principally at three Institutes of Forest Genetics at Placerville, California; Gulfport, Mississippi; and Rhinelander, Wisconsin. Additional genetics-related research is conducted in Oregon, Georgia, New Hampshire, Vermont, Illinois, Idaho, Florida, Louisiana, and Arkansas. The program involves cooperative research with numerous State agencies, universities, forest industries, and private foundations.

Substantial increases in appropriations for pest resistance research have made possible a doubling of the research effort. Forest Service programs in California, Wisconsin, and Mississippi have been augmented, and a large grant to Yale University will provide for the research needed to develop pines resistant to destructive sawflies. In addition, grants for basic research in genetics and breeding are in force under provisions of Public Law 480 in Finland, Poland, Greece, Italy, Israel, India, South Korea, Taiwan, Brazil, and Chile. The annual scientific effort directed to this research by the Forest Service is about 35 man-years.

Progress -- USDA and Cooperative Programs

1. Inherent Variation

Programs to select superior trees and to graft cuttings from them into seed orchards have developed rapidly in recent years. These programs were based on general information and suppositions about the heritability of characters. Now the earliest progeny tests are beginning to provide meaningful data. Two open-pollinated slash pine progeny tests in Georgia were examined at ages up to 9 years from seed. Heritability values were obtained for height growth up to 37 percent, diameter growth up to 37 percent, height of natural branch pruning up to 64 percent, and crown width up to 19 percent. Significant genetic improvement in these important characters should be possible through selection and breeding based on the new information obtained.

Geneticists are breeding slash pines for resistance to fusiform rust which causes severe losses in the South. Progenies from rust-free and rust-infected parents have been exposed to intense rust infection in Mississippi. Infection in progenies from two rust-free parents was about 50 percent in contrast to 90 percent infection in progenies from other parents. The results confirm our earlier finding that rust resistance is heritable. Further, they justify the practice of excluding all rust-infected trees from slash pine seed orchards.

In the Northeast, the white pine weevil is the major cause of declining production and use of the valuable eastern white pine. The first progeny tests examined for weeviling show that resistance to this insect is genetically controlled. This finding points the way to a breeding program to develop weevil resistant white pines.

Geneticists have known for some time that self-pollinating or inbreeding a seed tree generally produces slow-growing seedlings and trees. They have predicted dire consequences of using inbred seed. Measurements of 9- to 12-year-old inbred and outcrossed western white pine progenies in Idaho show that survival of the inbreds was reduced 13 to 20 percent; height was reduced 22 to 43 percent. These findings emphasize the importance of not collecting seed from isolated seed trees where inbreeding is likely. In the nursery, slowest-growing seedlings should be culled because they are likely to be inbreds that will continue to grow slowly.

Simply inherited traits are not frequently discovered, but they are useful to geneticists in studies of problems like the occurrence of selfing in orchards and natural stands. Studies in Pennsylvania indicate that dragon-eye marking, characterized by a yellow band at the needle base, is controlled by a single recessive gene in Japanese black pine.

High priority is being given to genetic improvement of eastern cottonwood as planting of this fast-growing species expands. The relationship between sex and desirable characters was studied in natural stands in the Lower Mississippi Valley. Male

trees were found to be significantly taller than female trees, but only slightly larger in diameter. This confirms for cottonwood the male-superiority in growth found for other poplars. Form class, stem straightness, branchiness, and specific gravity of the wood were not related to sex of the tree. Thus, sex of the trees has to be taken into consideration only when trees are being selected and propagated for height growth.

Other studies of cottonwood show that breeding for straight, vertical stems will improve wood quality. Wood from leaning and crooked trees was found to be more variable in structure, strength, and specific gravity. Furthermore, it was prone to buckle, split, twist, and collapse. Selection and breeding for the highly heritable trait of vertical, straight stems must be given high priority in any cottonwood improvement program.

Pines frequently exhibit unnatural growth when moved from their native habitat or seed zone to another. Often abnormal late flushes of growth will follow the normal bud break and shoot elongation. Late growth influences tree height and form, and stem volume. Further, it may expose the tree to damage from unseasonal climatic extremes of cold or drought. A comprehensive study has been completed of late growth of jack pines from 29 geographic locations in northern Minnesota and Wisconsin. Late growth occurred more frequently on trees from more southerly or warmer sources. The tendency to late growth was shown to be highly heritable and controlled by more than a single gene. The pattern of variation in abnormal growth was studied in natural jack pine stands. The results show that seed collectors should avoid general regions and particular stands where abnormal growth occurs frequently. Local environmental conditions of temperature and day length where the trees are planted also have a significant effect on late growth. Experiments using artificial long days showed that late growth is at least partially due to change in photoperiod. The general conclusions from this study are that seed should not be collected from trees displaying a tendency to late growth. Neither should seeds be moved very far north of the zone of collection. Failure to observe these guidelines is likely to result in trees with frost rings in the wood, excessive numbers of branches and knots, plus frequent occurrence of thick, upright, ramicorn branches.

A large investment in southern pine seed source studies is beginning to pay off. Numerous publications report source differences in survival, growth, and resistance to insects and diseases like brown spot and fusiform rust. Tentative guidelines for preferred directions to move seed of the principal southern pines have been based on the latest findings. Land managers can use these new guidelines to maximize productivity of their planted forests.

A Douglas-fir heredity study, now a half century from seed, is the basis for much of what is known about seed source differences and heritability of traits in Douglas-fir. Growth differences between races and between families within a race are

economically significant. Some families produced double volume of others from the same locality. Such variation gives assurance that worthwhile improvement in tree volume can be attained through application of genetics. Families usually showed good growth and survival only at a particular locality. Superiority of the same genetic stock over a wide range of environments was rare. Thus, the study cautions against making progeny tests in other environments than where the trees are to be grown.

Many facts, concepts, and opinions on geographic variation within tree species have emerged over the past 140 years. General conclusions from past research and procedures for comprehensive studies of genetic diversity within species have been brought together in a summary publication. This summary provides a checklist for scientists designing new provenance studies.

Forestry in the tropical and sub-tropical regions of the United States is concerned with trees not commonly known or recognized by foresters. Compiled in a new book are descriptions of the distinguishing characters, size, appearance, wood uses, and distribution of 250 common native trees of Puerto Rico and the Virgin Islands. Another 130 species related to these also are included. This reference text should be valuable to foresters, teachers, students, and others who are interested in tropical American timber trees.

One way of reducing losses to forest pests and of avoiding repeated use of harmful pesticides is to develop strains of trees having inherent pest resistance. Summary publications report notable progress toward poplars resistant to a number of diseases and pines resistant to rusts, weevils, and bark beetles. These also provide guidance for the new genetics programs seeking to develop pest resistant trees.

2. Hybridization

Hybrids, being new genetic combinations of the traits of the parent species, must be tried under a variety of environments to determine their range of adaptability. Eight hybrids and native pines were planted in 1950 at 5,280 to 6,420 feet in the central Sierra Nevada of California. After 12 years, the most promising hybrid was the backcross Jeffrey x (Jeffrey x Coulter). It showed little damage by insects, snow, or porcupines. This backcross hybrid, now being bred for outplanting on National Forests in California, should be an acceptable substitute for ponderosa and Jeffrey pines up to about 6,000 feet.

Characters of trees are determined by genes located on chromosomes. Characters may change dramatically if changes occur in the number of sets of chromosomes, called polyploidy, or in the presence or absence of single chromosomes, called aneuploidy. Chromosome studies of red and silver maples and their hybrids disclosed red maples with 6, 7, or 8 basic sets of chromosomes and with aneuploidy. Aneuploid hybrids between red and silver maples also were found. Discovery of these conditions opens up possibilities for cytogenetic breeding of red and silver maples with a variety of characteristics.

Incompatibilities preventing hybridization among pine species may be related to the biochemistry and physiology of pine pollens. Considerable research on pollen has been conducted in California and in the Netherlands by one of our scientists on a fellowship. One study using electrophoresis showed no differences among the albumin and globulin proteins in pollen of eight species and hybrids. Thus, major protein differences probably do not cause incompatibility. Other studies of pollen during the first few minutes after wetting show that the pollen grain is able to metabolize external substrates such as would be provided by the maternal tissues. High levels of non-protein flavanol-like substances diffuse from pollen during the first few minutes. These three findings suggest that factors other than protein may produce the incompatibilities that limit hybridization.

3. Methods Used in Tree Breeding

Forest managers find it difficult to decide on the need for or direction of applied tree improvement for their lands. Two publications for the Central States and Mississippi Valley bring together pertinent research information and suggest tree improvement methods that should be followed for cottonwood, other hardwoods, and conifers. The guidelines given should help forest managers start toward improving the genetic quality of planting stock of valuable fast-growing species in these regions.

Another study of cottonwood in the Mississippi Valley has shown how cold weather during winter influences forced flowering of this species. Branches collected on November 15 failed to flower immediately, but they did flower slowly after cold storage for a month. Branches collected in December, January, and February all flowered, and flowering time became shorter as exposure to cold temperatures increased. Male trees flowered 3 to 11 days sooner than females, but individual trees of each sex varied considerably in flowering time. These findings show cottonwood breeders how to extend their breeding work over a period from late January to late March.

Considerable controversy exists among forest geneticists about the advantages and disadvantages of clonal and seedling seed orchards. In Georgia, a seedling seed orchard of open-pollinated slash pine progenies has been measured and then rogued to leave the most disease resistant and best-formed trees. A poorly stocked orchard with very irregular spacing remains after 7 years. Seed production per acre is likely to be impaired. To develop a seedling orchard on this model would be inappropriate, but the choice of seedling or clonal orchard cannot be resolved on this study alone. The choice of methods will be dictated by time factors, progeny testing, and other requirements. Generally, clonal slash pine orchards are to be preferred if quick and abundant seed production are dominant requirements. Seedling orchards need more study before procedures of establishment can be recommended and genetic gains can be predicted.

Unique trees can be used immediately in genetics studies or in planting programs if they can be vegetatively propagated cheaply and in large numbers. Great quantities of genetically identical plants could be produced if the needle fascicles on a pine could be grown into plants. Studies at Rhinelander, Wisconsin, show that jack pine can be successfully raised from rooted needle fascicles providing the fascicles are taken from young trees and possess well-developed buds.

Other studies of the physiology of rooting needle fascicles are being conducted under PL 480. In Chile research has progressed to the point where serious consideration is being given to mass production of rooted fascicles of superior Monterey pines.

Rooting of cuttings becomes more difficult as trees from which the cuttings are taken grow older. Sprouts produced by older trees when they are cut or exposed tend to become juvenile in character and to root more easily. A preliminary study of sprouts taken from a pitch pine in Maryland indicates that 66 percent of succulent sprouts cut in September can be rooted.

Oaks are more difficult to root than pines, but a way of producing genetically identical oak twins has been developed in Illinois. The embryo in an acorn can be split with a razor blade. A high proportion of the embryo halves develop into seedlings. Identical twins produced in this way can be used to study the effects of environmental variations on identical genotypes.

Sweetgum is receiving increased attention of tree breeders who need a means of producing genetically identical clones. Cooperative studies in Georgia show how to propagate this valuable species from root cuttings. Of the cuttings taken in mid-June from 3-year-old seedlings, over 90 percent had produced buds and roots by October. Success ranged from 20 to 93 percent for cuttings from roots of 20-year-old trees. Production of clones from root cuttings will be useful to sweetgum breeders and to anyone wanting to produce large numbers of plants from a particularly desirable sweetgum.

Protecting control-pollinated cones in the tops of tall trees from insect attack is difficult and costly. An insecticide spray system for permanent installation in trees in forest stands has been developed in Arkansas. Rotating sprinklers were placed above the tops of trees with stand pipes running to the base at a cost of about $12.50 for parts. In five minutes the pipe in a 100-foot tree can be connected to a power sprayer, and the spraying can be completed. First results show that insect-infested cones can be reduced from 55 to 15 percent. The costs are reasonable when a selected tree is bred for 4 or 5 years.

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D. TIMBER-RELATED CROPS

Problem

The forests of the United States produce a number of timber-related forest crops, some of which are sources of important industries in different parts of the country. These products include naval stores, maple sap, Christmas trees, and a group of minor crops composed of edible, medicinal, and decorative materials. Some of these crops, independently or in integration with timber production, greatly enhance the total income of forest owners. These crops also provide a ready cash income which is not easily obtainable from periodic timber harvests. Many of the minor forest crops provide supplemental income to individuals in low-income areas. The research problem is to determine the potentialities of these timber-related forest crops and to develop the most efficient methods for their production.

Another important area of research is to develop better types of trees and cheaper and more effective methods for establishing, maintaining, and improving shelterbelts on the Great Plains. Shelterbelts and related tree plantings improve the quality of the surroundings for people, and ameliorate the hostile local climate for crops, livestock, and farmsteads.

USDA and Cooperative Programs

The present program of Forest Service research in timber-related crops includes a project in naval stores production and related tree improvement research at Olustee, Florida, a project in the production of maple products and related tree improvement research at Burlington, Vermont, a project on production of Christmas trees and other timber-related crops from Appalachian forests at Berea, Kentucky, and a small amount of research on Christmas tree production conducted as part of silvicultural and genetics projects in Michigan, California, and elsewhere. Shelterbelt research is located at Bottineau, North Dakota, and Lincoln, Nebraska.

The naval stores research includes fundamental studies of the physiology of oleoresin flow and applied research on the improvement of gum extraction techniques. The extraction phase of the research will be coordinated with equipment development research in the forest engineering project of the Forest Service at Auburn, Alabama. The research on maple sap production involves studies of physiology of sap flow, maple orchard management, and the development of strains with higher sugar content and sap yield, all in cooperation with the University of Vermont.

Research in shelterbelts includes the selection and breeding of trees for better form and greater resistance to the severe climates. It includes techniques of planting and cultivation leading to higher survival rates and more rapid juvenile growth. Methods of maintaining the vigor and density of the shelterbelts over long periods of time are also under study.

Research on Christmas tree production includes the development of types of trees better adapted to Christmas tree use, as well as intensive cultural methods for diverse species, sites, and markets. Research on the miscellaneous timber-related crops such as greens and medicinal plants centers on ways to increase the supplemental income to forest owners from this source.

Forest Service research in these fields is closely coordinated with the naval stores and maple sugar processing of the Southern and Eastern Utilization Research and Development Divisions of the Agricultural Research Service. Some phases of the Christmas tree and maple sap production are studied by State agencies and universities often in cooperation with the Forest Service. Shelterbelt research is coordinated with work of the Crops Research Division and the Soil and Water Conservation Research Division of ARS and with work of the State Experiment Stations through the Windbreak Research Committee of the USDA, and Research Subcommittee of the Forestry Committee of the Great Plains Agricultural Council.

The annual Federal scientific effort devoted to the research by the Forest Service is 16 professional man-years.

Progress -- USDA and Cooperative Programs

1. Naval Stores

For some years the accepted method of turpentining southern pines has included spraying a 50-percent solution of sulfuric acid on the fresh wound to prolong the flow of oleoresin. This method halves the necessary frequency of wounding, but the acid is hazardous to workers and corrosive to the metal cups and gutters used for gum collection. Recent research indicates that these hazards might be avoided by substituting 2, 4-D for sulfuric acid. A 4-year comparison of the two stimulants showed that a 2-percent solution of 2, 4-D provided just as much gum yield as sulfuric acid. Corrosion of metal cups and gutters was greatly reduced. With sulfuric acid, iron contamination from the corroded metal progressively lowered the grade of gum after the first year, whereas with 2, 4-D the grade of gum remained high over the 4 years of operation. The 2, 4-D solution kills longleaf pine, but its use should improve naval stores practice on the large acreage of pure slash pine plantations now coming into production for naval stores.

Another approach to cheaper gum production is the use of acid paste to replace acid solution as a gum-flow stimulant. The paste keeps the acid in contact with the wound longer, and keeps most of it from contact with metal cups and gutters. As a result, gum flow is prolonged, and the corrosion of the metal is reduced. Over a period of three season's use, just as much gum was obtained from a 3-week wounding interval with paste treatment as from a 2-week interval with acid solution treatment. The paste also permitted a 4-week wounding interval with only 15 percent reduction in gum yield per tree. Research is continuing on formulation of pastes and on techniques and equipment for applying them.

Plant breeders often use simply inherited visible traits to learn more about inheritance of commercially important characters in plants. Two such traits have been found in progenies of slash pine in the tree breeding program for oleoresin yield at Olustee. These traits have been used to learn about inheritance and self fertility in this important species. Selfing and outcrossing of a tree-producing yellow oleoresin showed that this trait was inherited as a homozygons recessive, but the number of genes involved has yet to be determined. Controlled breeding on two other trees, having chlorophyll-deficient or virescent foliage, showed that this trait was also inherited but the exact mode of inheritance could not be determined. These traits are useful "gene markers" that can be detected at a very early age. During the next year this type of research will be extended to determine the mode of inheritance of the constituents of turpentine in slash pine.

Self-pollination is one problem that may occur in slash pine seed orchards containing relatively few high-gum-yielding clones. A high proportion of self-pollination is undesirable because the resulting inbred progenies will have depressed growth and other undesirable characters. Under controlled breeding, the degree of self-fertility varied greatly among high-gum-yielding pines, but it averaged about 18 percent of cross-fertility. Mixtures of self and outcross pollens on three mother trees having gene markers (yellow oleoresin or virescent foliage) showed that neither selfing nor outcrossing was favored. The results suggested that the degree of selfing in seed orchards will depend greatly on the number of clones used and on the degree of self-fertility of the clones. A slash pine orchard containing at least 20 clones will probably produce only a slightly greater proportion of selfs than that which occurs in natural stands.

2. Maple Sap Production

Searching for sugar maples having high sap sugar is difficult because little is known about influences of heredity and of environment on this trait. New survey and selection procedures have been developed to minimize influences of environmental factors. They also will show tree-to-tree variation in sugar content. Between 50 and 150 trees are sampled in each selected sugarbush. A superior tree for sweetness must exceed the sweetest of four comparable neighbor trees by 0.5 percent sap sugar, and it must be at least 30 percent above the average of its neighbors. One test alone does not suffice. Selected trees are tested four more times during two seasons. Superior trees must continue to produce sweeter sap. These new procedures have been adopted by cooperators in Maine, Vermont, New Hampshire, and New York in a unified search for sweeter sugar maples.

Superior sugar producers found in the survey must be vegetatively propagated before sap yield, wood quality, and other traits can be studied further. Early attempts showed that greenwood cuttings can be rooted, and this technique is being refined through recent studies. Greenwood cuttings taken in June produce roots consistently

in 8 to 10 weeks. However, mortality of rooted cuttings during the first winter is very heavy, about 80 percent. Physiological studies are concentrating on solving the problem of over-winter survival.

3. Shelterbelts

Shelterbelts do not last forever, and new problems arise as they grow older or are damaged. New studies in Nebraska attempt to find ways of relieving suppression and crowding in wide 10-row shelterbelts. Other studies seek ways of repairing severe damage by livestock grazing and failures of certain tree species. Single-row shelterbelts are being evaluated to find the best species, spacings, and cultivation procedures. In shelterbelts that have grown up so that the lower part is now open, cutting out a row of hardwoods will improve the lower density. The cut stumps sprout vigorously and the sprouts rapidly fill in the lower story of the shelterbelt. Results of these studies should prolong and restore the sheltering influence of older tree plantings, and they should point the way to more efficient future shelterbelts.

Tree species and individual trees display a variety of characteritics influencing their desirability for use in shelterbelts. A guide has been prepared to assist field technicians in recognizing superior shelterbelt trees. Traits such as growth rate, crown density, width of crown, angle of branching, time of leafing and defoliation, straightness of stem, and resistance to drought, winter injury, insects, and disease are defined and illustrated.

Past shelterbelts have been made from selected species but not of select trees. A new search has uncovered better types of ponderosa pines for planting from north to south over the Great Plains. Comparative studies of these types are being installed at six locations from North Dakota to Oklahoma. They should point to the best sources of ponderosa pine seed for future shelterbelts.

An unusual shelterbelt is proposed for Hawaii to control giant ocean waves. Barriers of trees have been proven effective in reducing damage along exposed sea coasts of Japan. Our scientists, adapting this concept to Hawaiian conditions, have proposed a "tsunami control forest" for the oft-damaged waterfront at Hilo.

4. Other

Although the best sites are usually selected for growth of other tree crops, highly fertile sites are not desirable for Christmas trees. Such soils cause too rapid growth of the trees, requiring shearing to produce a merchantable tree. These soils also produce a rank growth of weeds which shade out the lower crowns and are a fire hazard. In southeastern Ohio, the best sites for growing Christmas trees are abandoned fields, on acid residual shale or sandstone soils, carrying a light cover of poverty grass or broomsedge.

Drug and other plants cultivated and harvested in Appalachian forests might be a source of supplementary income to forest residents. Hundreds of plants used for home remedies are recognized by medical authorities as having therapeutic values. Common periwinkle, ginseng, digitalis, may-apple, and boneset, are among the best known and most valuable. A new research project at Berea, Kentucky, is analyzing the demand, production requirements and potential, and profit possibilities for the most important wild drug plants. Christmas trees and decorative plants also are receiving increased attention in this new project. The overall program is aimed at increasing the contribution of forest lands to the economy of Appalachia.

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II. WATERSHED, RECREATION, AND RANGE RESEARCH

A. FOREST SOIL AND WATER RESEARCH

Problem

All of the major rivers of the United States have headwaters in forests, associated rangelands, or alpine regions. To derive the greatest benefits and protection from these headwater areas, improved knowledge of the management of watersheds and streams is needed. More than half the waterflow of the country originates in such areas. Whether this waterflow is beneficial or harmful, is well-regulated, sustained flow of good quality or erratic and silt-laden is contingent to a major degree upon how the headwater lands are managed. Generally accepted estimates of water use indicate a doubling in demand by 1980. The most logical place to look for additional supplies of high-quality water, or to improve timing of streamflow, is in the headwaters. At the same time, there are constantly increasing pressures to use watershed lands for a variety of other products and services. Watershed management research is providing information needed to determine how to best adjust these several uses to give the necessary protection and development to soil and water resources.

USDA and Cooperative Programs

This work includes basic and applied research into the relationships of soil, climate, vegetation, and water and the development of methods and techniques to: (1) increase water yields or improve the timing of such yields under a variety of climatic, soil, geologic, vegetative, and topographic conditions; (2) give adequate protection to soil and water resources while forest and related rangelands are being used for timber production, grazing of domestic livestock and big game, wildlife habitat, mining, and forest recreation; (3) rehabilitate forest and related rangeland watersheds that constitute sources of damaging flood runoff and sediment; and (4) aid forest soil development and improvement.

One hundred and one (101) professional man-years of effort were expended on this research during the past year.

Progress--USDA and Cooperative Programs

1. Water Yield Improvement

Research in the improvement of water yield is conducted in the different terrain, climatic and forest vegetational complexes throughout the Nation. The purpose is to explore the opportunities for improving the amount and/or timing of water yield through manipulation and management of the Nation's forested and related range and alpine watersheds. Water yield improvement research is being done in (a) alpine snowpack zones of the West, (b) forested snowpack zones of the East and West, and (c) in nonsnow forest areas. Research results are discussed under these breakdowns.

a. Alpine snowpack zone. The alpine zone includes the area above timberline. The climate is cold and winds move the snow about continuously. Snow cover is seldom over two feet deep except for protected pockets in ravines or behind obstructions where the snow may drift to depths of 30 feet or more. The drifts melt slowly in the summer, maintaining streamflow long after lower elevation snow has melted. Since evaporation losses from these snowpacks are negligible compared to evaporation losses from lower elevation reservoirs, storage of water in snowdrifts until mid- and late summer may increase storage efficiency.

Alpine snow research is primarily concerned with the aerodynamics of wind transport and deposition of snow. The goal is to improve the timing of water yield from this important zone by inducing more deep drifting of snow and increasing late-season streamflow. The benefits of building snowfences along main ridge lines have been demonstrated in Colorado. Application of 8-foot high snowfences has increased natural storage to the extent that an extra acre-foot of water per each 100-125 feet of snowfence is available in storage as late as July 1. This is considerably more fence than was indicated by earlier results but has the effect of extending the period during which direct snowmelt runoff is available by about 2 weeks.

Avalanches are inevitable with deep snow in steep terrain. The increases in winter sports activities and winter travel into the mountains have increased the avalanche danger to life and property. Some of our research on passive avalanche protection is to learn how to stabilize snow in avalanche areas. In a study of the influence of weather factors on the occurrence of slab avalanches, wind was found to be the most significant factor leading to the formation of direct-action slab avalanches. Also, avalanches were found to be most prone to release when air temperatures were below 27° F.

b. Forested snowpack zone. Below the alpine area lie the forested and brush watersheds which accumulate snow and supply much of the streamflow of the western mountains and in north and northeastern sections of the country. In the West, excellent opportunities prevail for improving water yields from this zone through management of the forest vegetation. Annual precipitation averages 30-50 inches of water, 45 percent of which appears as runoff. Preliminary studies of cutting patterns and other forest management practices which reduce interception and evaporation losses and increase the snowpack indicate possible increases in water yield as much as 4 inches (20 percent). Little is known about the effect of various forest densities, cutting patterns, slope direction, climatic characteristics, etc. upon snow accumulation, ripening, and melt.

A special sequence of timber cutting designed for maximum snow accumulation and delay of melt has been applied to a logging operation in the California Sierras. Logged strips are so oriented to minimize direct exposure of the snow cover to the sun and minimize re-radiation from the residual stand onto the cut strips. During two years following treatment, snow water content in the clearcut strips has averaged 43 percent greater than in the adjacent uncut forest. At maximum accumulation in 1963, clearcut strips contained a snowpack water equivalent of 27 inches, partially cut strips 22 inches, and uncut forest 19 inches.

In conjunction with the above timber-cutting study, snow evaporation suppressants to reduce snowpack water losses are being investigated. Hexadecanol, a long-chain fatty alcohol forming a monomolecular film when applied to water surfaces, caused reductions in evaporation from open-area melting snowpacks of 86 percent. Hexadecanol did not significantly influence the rate of evaporation from snowpacks under a forest canopy, however.

Continuing assessment of the role of forest vegetation in the hydrologic cycle is pointing out that even obscure relationships may be of significance to the influence of forests on water yields. During the passage of winter storm systems, considerable quantities of rime ice are caught and trapped by the canopies of high-elevation spruce and aspen in northern New Mexico. The smaller branches of aspen may intercept three or four times their volume in rime ice during a single storm. Measurements of rime ice falling from forest trees to the snow surface showed falling rime from one storm had an average water equivalent of 0.20 inch. Rime fall from spruce canopies amounted to 0.09 inch. During an average winter season of several rime-producing storms, it is possible that an additional inch of water may be added to the snowpack.

After 5 years the average increase in streamflow resulting from conversion of moist-site and riparian forest vegetation (white fir and Douglas-fir) covering one-third of a 248-acre watershed in central Arizona to perennial grass is 55 percent. This compares with an average increase of only 4 percent from a companion watershed where 35 percent of the basal area of trees was removed by an individual tree selection harvest over the entire watershed. Apparently in this latter watershed the roots of remaining trees spread out to consume most of the available water.

Objective methods of separating total storage changes into seepage losses, evapotranspiration losses, and recharge from precipitation were recently developed as an aid in relating forest cover conditions to water yields in glacial outwash sands on the lower peninsula of Michigan. Application of these methods to water table data collected over a 2-year period of near-normal annual rainfall showed that hardwood forests had net ground-water yields approximately equal to the 15-inch annual runoff measured in nearby rivers. Twenty to 30-year-old jack pine and red pine plantations yielded approximately 3 inches less water per year during the same period. These differences are associated with high water losses from snow interception during the winter, and early spring transpiration drain from the pine forests.

Reduction of summer transpiration draft following reduction of vegetation density is observable in studies of soil moisture depletion rates. These studies serve to illustrate the magnitude of potential water yield increases and quantify the factors which govern or regulate seasonal use of stored soil moisture.

Aspect, elevation, and age of aspen and gambel oak stands were evaluated as factors affecting soil moisture depletion near Ephraim, Utah. Mature stands and developing sprout stands of both species were studied at two elevations on north, south, and west aspects. Soil moisture measurements under oak show that more water was used by mature stands than by sprout stands on all aspects at both elevations during early summer, but there were no differences in late summer. Little difference in water use between elevations was apparent on north and west aspects, but on the south exposure the high-elevation clone used nearly twice as much moisture as the lower clone. This difference is primarily attributable to deeper soils, and consequently greater moisture storage, at the higher elevations.

Aspen clones appear to be more variable than oak and vary more widely in moisture use. Considerable soil moisture was conserved on some sites by aspen removal while other sites showed little change. Removal of aspen caused higher moisture losses from surface soils, but conserved moisture stored in the deeper horizons. As with oak, greatest moisture losses occurred early in the growing season, especially from mature trees.

The role of soil depth in governing potential water yield resulting from manipulation of vegetation is further illustrated in a study in the eastern Cascades in Washington. Lodgepole pine occurring on soils 2-3 feet deep utilized 2.5 inches of soil moisture during the drying season, while 6.4 inches were lost from soils 6 feet or more deep. Clearcutting lodgepole pine from the deep soils will result in a large reduction in evapotranspiration loss and higher soil moisture storage, and presumably will make more water available for streamflow.

Preliminary analysis of June-October soil moisture depletion from a forest area clearcut of mixed conifers in the lower zone of the Sierra Nevada revealed that 5.6 inches of soil moisture were removed from soils 20 feet deep, while during the same period uncut stands used 21.4 inches of soil moisture.

An automatic system has been devised to record heat pulse velocities, an index to velocity and direction of sap movement, in tree stems at preselected time intervals. In both Engelmann spruce and lodgepole pine, most rapid rates have been observed during snowmelt when soils are thoroughly wet. Sap velocities later in the summer are reduced, indicating that even with old, well established trees soil moisture controls water use more than any other factor.

c. Nonsnow forest zone. The concept of water yield increase or change in timing of streamflow is based largely upon the fact that plants use water. By varying the density, spacing or arrangement of certain species, the amount of water used by vegetation may be manipulated, thus influencing the volume of water delivered to streams.

Selected climatic, topographic, and land-use variables have been related to streamflow characteristics in Northeastern United States to determine which factors most significantly influence water yields. Average annual and seasonal runoff, as well as daily mean discharges at selected flow durations, were analyzed for 137 watersheds smaller than 100 square miles in area. The most significantly related factors, in descending order, were found to be: precipitation, percent of forest cover, July maximum temperature, elevation, latitude, percent of open land, and percent of swamp lands. Isohyetal figures for precipitation were more highly correlated with average annual runoff than precipitation values from the closest station.

On the Sacandaga River watershed above Hope, New York, a gradual one-directional change in land uses and an increase in forest cover have been correlated with changes in annual, dormant season, and April streamflow over the period 1912-50. In 1912, total forest stand density and density of conifers on the watershed were probably at an all-time low level following widespread logging, insect outbreaks, and wildfires. As the forest density and crown cover of conifers increased up to 1950, the average annual streamflow decreased 7.7 inches, with a 5.2 inch decrease in dormant season runoff. This indicates greater amounts of water are required to replace water removed by evapotranspiration and recharge the soil mantle.

The effects of complete removal of forest and herbaceous vegetation on water yield are being studied on two 60-acre watersheds on the Fernow Experimental Forest in West Virginia. Following removal of all commercial material, the iso-octyl ester of 2,4,5-T is used as a dormant season basal spray and as a growing season foliage spray. Measurements of vegetation show that this treatment has eliminated about 98 percent of the foliage. Treatment will progress in two stages; to date, half of

each watershed has been treated. Preliminary analyses of results show that, for the half-watershed where treatment is in effect, water yield has been increased 7 area-inches during the period May-October. No detectable deterioration of water quality has been observed during or after herbicide applications.

On the western slopes of the Oregon Cascade Range, streamflow is strongly influenced by a maritime climate. Although annual precipitation is high (90 inches or more), overland flow is virtually unknown. Peak flows result largely from subsurface flow and vegetation exerts a minimum influence. This is because peak flows follow a condition of maximum soil moisture storage, reached during extended periods of low intensity rainfall. Low streamflow occurs from late August to mid-November and may follow a 60-100 day dry period. At this time dense stands of Douglas-fir exert a major influence. Removal of vegetation from only 30 percent of a 250-acre watershed has increased minimum streamflow 12 to 28 percent. Removal of 80 percent of the vegetation from another watershed has increased low flow by 85 percent.

Reduction of water vapor losses through temporary defoliation is also being tested at the Coweeta Laboratory as a possible means of improving late-season streamflow. Trees on forest soil plots, plastic-covered to isolate losses due to transpiration, were chemically defoliated in 1962. Analysis of subsequent soil moisture levels revealed that about 1.5 inches of water migrated into the upper 6 feet of soil mantle while 1.3 inches were lost from underlying horizons. These results indicate that defoliation may not result in increased streamflow if postponed until surface soils are dried by normal, uninhibited evapotranspiration.

2. Prevention of Watershed Damage

a. Timber management. There are many thousands of acres of forest and related lands that are in good watershed condition. Increasing demand for use of these lands for timber harvesting, grazing, recreation, and wildlife requires that special attention be given to maintaining stable soils and controlled streamflow. Research in this area involves development of land-use practices that give special attention to the prevention of watershed damage.

Loose granitic soils of central Idaho and western Montana have rather high rates of natural erosion, depending upon exposure of slopes. This is revealed by a study of natural rates of erosion and of changes brought about by timber removal. Immediately after roads were constructed in the area heavy soil losses occured, but careful logging of the area by either high lead or jammer methods did not cause any increase in soil losses. On the other hand, exposure of slope made a lot of difference. Southwestern exposures yielded eight times as much sediment, on the average, as northwest exposures. Also, erosion during the May-September half of the year was 2.5 times as great as during the September-May period. There is evidence from other areas that these differences are greatly accentuated by careless logging and road building that disturbs the soil surfaces. Furthermore, this study emphasizes that site differences must be taken into account early in the development of management plans.

To this end, the physical properties of wildland soils derived from three different parent materials in central Washington, sampled by horizons under forest and adjacent grass cover, were analyzed for water-stable aggregates, bulk density, organic matter, pH, porosity, and texture. The analyses indicated that forest and

grass covers were associated with soil property differences, but the relation of these differences to parent materials and horizons is not consistent. A large part of the variation in soil erosion hazard, as measured by mean size of water-stable aggregates, was accounted for by interactions between organic matter content, pH, porosity, and bulk density.

Similarly, water-stable aggregates of Hawaii soils have been found to be predictable from characteristics of the site where the soil was formed. Multivariate analysis techniques related soil characteristics to soil-forming factors of vegetative type, precipitation, elevation, and parent material. As these factors account for the bulk of the variation in Hawaii soils, a map of soil characteristics can be made from maps of precipitation, topography, geology, and vegetative types.

Through a system of sampling subsurface stormflow from the various layers in a soil, measurements of five simulated storms in 1964 showed that initial seepage came from the coarse-textured soil immediately overlying the finer-textured flow-impeding layer. As a storm continued, the zone contributing flow grew larger and built up above the impeding layer. But, the wetted zone did not build up along a uniform line; the general line of saturation followed closely the large-sized biological and structural holes and cracks. Greatest quantities of flow issued from these openings rather than from the general zone of saturated soil. This reaffirms the belief that interconnected root channels, cracks and fissures, when saturated, are the primary transmission routes for subsurface stormflow water. Thus, it is possible that subsurface stormflow from undisturbed forest soil behaves somewhat differently from the interflow from more uniformly textured and structured agricultural soils or those in airports or golf courses.

b. Logging road location and construction. A large proportion of sediments reaching stream channels from forested lands originates from roads. In the construction and maintenance of roads, soil disturbance is inevitable. Yet, roads are a necessary part of the process of converting overmature timber to managed stands. And, as logging pushes further into the steeper, more inaccessible forests, soil disturbances from road construction will increase. Procedures are being developed for minimizing erosion from road surfaces, restoring stability to fill slopes, and regaining overall absorptive capacity of disturbed soils as quickly as possible.

A major requirement in the design of logging roads is the provision for proper and adequate drainage to prevent erosion of the road and consequent streamflow deterioration. Drainage water has two main sources: overland flow from intercepted precipitation, and seepage flow from adjacent cut banks. Overland flow volumes are a relatively predictable function of precipitation intensity and infiltration capacity of the road surface, but volumes of drainage water from seepage are more difficult to predict.

Comparisons of seepage flow from roads traversing uncut and clearcut blocks at 6400 feet elevation in the Engelmann spruce-fir type show maximum hourly seepage flow rates per mile of road traversing clearcut and uncut areas to be 4.60 and 5.96 cubic feet per second, respectively, during the snowmelt period. Maximum daily seepage volumes per mile of road amounted to 6.13 acre-feet in the clearcut blocks and 5.17 acre-feet in the uncut. The hydrograph for the road in the forested block is generally subdued and less abrupt than the one representing the clearcut block. Seepage-flow peaks for the forested area are smaller than those for the clearcut

blocks. During the snowmelt period the daily upsurge of seepage flow begins and ends sooner, and reaches a higher peak, in the clearcut areas. Tree cover in the uncut stands distributes radiant energy more evenly throughout the day to maintain a more uniform flow over a longer period.

Geophysical exploration techniques are also valuable adjuncts to proper road location and design. These methods, based on principles of seismic refraction and electrical resistivity, have been demonstrated to be helpful in predicting the type of earthen materials likely to be encountered during construction and in evaluating the uniformity of subsoil and geological conditions. A portable seismograph was used to determine depth to bedrock beneath a study area having a recognized groundwater seepage problem. Seismic traverses showed the cause to be a relatively shallow bedrock which forced ground water to the surface.

c. Range management. Forest-associated rangelands are a primary source of waterflow. They also provide needed forage for big-game herds and large numbers of domestic livestock. Continued grazing use of these lands is dependent upon recognizing or establishing plant cover requirements for maintaining stability on these sites.

Past research on site factors that influence infiltration and soil stability has emphasized the importance of plant cover in runoff and erosion control. Recent studies of infiltration and erosion have included evaluation of soil physical properties, topography, and vegetative characteristics. The single site factor most closely correlated with total water intake was bulk density of the surface inch of soil, but when combined with other site factors, bulk density of the surface 4 inches was even more influencing. Seven other variables contributed to the variance in total infiltration. They are: clay content of the surface inch of soil, air-dry weight of vegetation, air-dry weight of litter, capillary porosity of the 1- to 2-inch depth, soil organic matter at the 4- to 6-inch depth, plot slope-gradient, and aspect. The proportion of ground surface exposed as bare soil was the site factor most closely related to rate of soil loss. Plot slope-gradient was a lesser but yet important factor influencing rate of soil loss.

Preliminary results of a study in Utah designed to evaluate the hydrologic effects of grazing high-elevation mountain ranges indicate that the amounts of plant and litter cover on the ground are reduced by cattle grazing, and these reductions are attended by decreases in infiltration capacity without significant changes in soil bulk density. On the other hand, infiltration capacities decreased in both ungrazed exclosures and grazed areas from the spring, when soils were moist, to late summer when soils were dry. These decreases were accompanied by significant increases in soil bulk density. Thus, ground cover conditions as influenced by grazing use, and soil bulk density as influenced by moisture content, appear to have significant effects on the hydrologic characteristics of livestock range.

3. Rehabilitation of Damaged Watersheds

This research is designed to develop techniques and management practices which will restore satisfactory surface flow and streamflow conditions and stabilize and improve soils on forest and range watersheds that have been damaged through past use and remain in unsatisfactory condition.

a. Abandoned farm lands. In years past, many thousands of acres in the piedmont and upper coastal plain of the Southeast and South and other areas in the Lake States and the Central States were cleared from forest and put under clean cultivation. Serious erosion and lowered productivity of the land have resulted in abandonment of many areas. Difficult problems now prevail to stop the active erosion and to reestablish trees and other protective vegetation on those lands.

Inherent resistance to frost damage is important in selecting tree species for rehabilitation of abandoned farm lands in southwestern Wisconsin. A recently completed study shows black walnut, white oak and red oak to be quite susceptible to late-spring frost damage in second and third year plantations. Norway spruce, white spruce and European larch were moderately sensitive while jack, ponderosa, red, white, and Scotch pines were found to be frost-hardy.

It is generally held that frozen ground is relatively impermeable to infiltrating water. In February 1965 open land on the Coulee Experimental Forest in southwest Wisconsin was frozen to a depth of 2 feet. Frost surveys of wooded slopes showed that the ground was frozen at 85 percent of the sample points to depths ranging from 1 to 16 inches. During a 3-day February thaw, springflow increased at a rate which indicated that a significant amount of snowmelt water had infiltrated to the ground-water table.

These soil-water relations during winter are substantiated by similar observations in Arkansas. In the upper 15 inches of two frozen soils, one bare and one under a cover of alfalfa, winter moisture contents usually exceeded the pre-freeze field maximums. Total pore space was always above, and bulk densities below, the pre-freeze levels. Winter moisture changes in these frozen soils were attributed to internal moisture movement.

b. Damaged rangelands. Overgrazed rangelands in Western United States are often important sources of floods and erosion. Rangeland soils are often thin and sites are harsh. Past efforts to reestablish protective vegetation have frequently failed. Research in development of new and better procedures for rehabilitation is underway in several areas.

The restoration program installed on the Davis County experimental watershed in northern Utah during the 1930's was an outstanding success in accomplishing control of torrential mud and rock flows. However, no measurements were made during or after the installation of contour trenches to determine their infiltration or sedimentation characteristics, or how these characteristics might vary with time, soils, or degree of vegetation reestablishment. A study is now underway to compare these characteristics for newly constructed contour trench sections in coarse, medium, and fine soil materials.

First year measurements show that average infiltration rates in these trench sections during the time required for them to completely drain were 15.8 inches per hour on coarse-textured soil material, 15.4 and 9.2 inches per hour on medium- and fine-textured soils, respectively. Differences in infiltration characteristics of trenches constructed in coarse and fine soil are more sharply reflected by comparisons of infiltration rates with respect to time. Initial infiltration rates for filled trenches ranged from 130.0 inches per hour for 3 to 5 minutes in coarse soil to 25.2 inches per hour in fine material. After several hours, when trenches were

about three-fourths drained, infiltration rates on these same sites decreased, respectively, to 12.1 and 0.6 inches per hour.

There is continuing effort to discover plants most effective for erosion control and to gain knowledge of methods of establishing them successfully for restoration of damaged range. In plot trials of plants suitable for rehabilitation projects in Colorado, New Mexican blueberry elder appears to be outstanding among 23 shrub and tree species tested for erosion control properties. Height after 4 years of growth from cuttings averages 65 inches. Average annual weight of litter production is 180 grams per individual plant, and no mortality has been observed to date. Other likely shrub species include Siberian pea shrub, Bessey cherry, and Russian olive. Among the grasses and forbs tested, several species of wheatgrasses have good erosion control qualities.

Soil renovation to curtail surface runoff and erosion, and at the same time encourage plant establishment and growth through increased soil moisture storage, offers promise as a range improvement technique. In the semidesert area of New Mexico, an evaluation of soil pitting and soil ripping as rehabilitation measures showed that subsoil ripping was more effective in reducing runoff and erosion than were surface depressions or pits. Ripping reduced surface runoff 85 percent and erosion 31 percent at the end of 3 years. During the same period, surface pitting reduced runoff only 10 percent and caused no significant reduction in erosion.

c. Strip-mined lands. There is a great surge of interest in the problems of strip mining among conservationists, land managers, and landowners. Forest Service research in the restoration of strip-mined lands has been increased to develop methods for minimizing damage during mining and for quickly establishing vegetation to reduce runoff and erosion and restore a pleasing and productive landscape after mining.

A 30-county survey of strip mining in eastern Kentucky is in progress. A field check to find the outslope area covered by tree canopy has been completed for parts of four counties, a total land area of 434,718 acres. Total area stripped is 10,107 acres or 2.3 percent of the area. Of the total area stripped, 99 percent was forested land and 95 percent was contour or rim type stripping. There were 122 miles of coal haul roads averaging 75 feet in width, for a total of 1,100 acres.

Extremely acid strip-mine spoils (pH below 4.0) are difficult to revegetate. Toxicities resulting from elements brought into solution by very acid conditions are a major cause of poor plant growth. Knowledge of the nature and location of geologic strata that contain acid-producing material is vital to solution of the problem. Chemical and fertility factors related to plant growth on spoils have come under intensive investigations during the past two years.

Aluminum is apparently the major element causing toxicity. Liming will correct this condition, but it may not be a feasible treatment. Mining practices which promote leaching of spoils with a minimum of surface evaporation will help to lower the concentration of aluminum in solution. Also, plants known to be tolerant of relatively high levels of aluminum can be selected for spoil-bank plantings, and in some cases fertilization of spoils with nitrogen and potassium may enhance plant growth. However, fertilizer could not be expected to increase plant growth at extremely high levels of acidity.

Other investigations have shown that only a small part of the soil materials overlying strip-mined coal seams have a pH lower than 4.0. Yet, half of the spoil banks on benches or outslopes formed by stripping operations have a pH lower than 4.0. This is partly due to the fact that the land surface being stripped slopes steeply. Materials immediately overlying the coal seam make up more of the spoil volume than might be assumed from observation of the highwall because placement of spoil material may result in a veneer of the most acid strata being placed over the bulk of low-acid materials.

These findings emphasize that care should be taken in the handling and covering of acid-producing materials during stripping operations. Identification and proper handling of spoil banks during mining will leave the area in the best possible condition for rapid restoration of productive forest cover.

d. Burned watersheds. Fire-induced floods and erosion from steep, unstable watersheds are a serious problem in some parts of the country--particularly in southern California. Records show that flood peaks can increase 68 times and erosion rates can increase 28 times following fire. Floods and erosion at greatly accelerated rates not only impair watershed productivity but also are a threat to downstream population centers. Methods for quickly stabilizing destructively burned watersheds are being sought.

On chaparral watersheds in southern California, there seems to be a condition imparting resistance to soil wetting. This condition has been shown to be a factor contributing to high rates of runoff and erosion from burned-over areas. Recent investigations have been aimed at determining the nature and influence of this hydrophobic substance.

Laboratory soil column experiments on evaporation phenomena indicate that the presence of a hydrophobic substance in soil can reduce evaporation substantially. Soil columns packed with a nonwettable soil lost 21 percent less moisture than columns filled with a similar textured wettable soil during an 89-day drying period. The reduction in evaporation was partially due to the formation of a "dry mulch" layer on the soil surface. In addition, upward moisture movement by capillarity from the lower ends of the soil columns was reduced by the nonwettable soil property. Infiltration trials were also conducted on horizontal columns. Data from these infiltration experiments were used to calculate unsaturated flow rates in the two soils. The analysis indicated that a hydrophobic substance becomes more instrumental in retarding unsaturated flow as a soil dries out.

During the preparation of wettable and nonwettable soil systems for the moisture movement experiments, it was observed that heating may affect the degree of nonwettability in a soil. Heating for 18 minutes at 700° F. destroyed the nonwettable property. However, heating for only 8 minutes at 200° F. intensified the nonwettable condition. Water drops would stand on the soil surface of the nonwettable unburned soil for 5-10 minutes before being absorbed. After exposing this soil to a light burning treatment, the water drops remained on the soil surface at least 4 hours. Further experiments are planned to investigate the effects of different burning time and intensities on the nonwettability in these soils.

4. Soil Improvement

There are more than 25 million acres of wetland forests ranging from the bogs of the northern Lake States to the swamps of the southeast coastal plains. Most of these lands are strategic headwaters for countless streams, and are recharge areas for ground-water supplies in certain localities, but they support only low-growing heaths or degenerate forests. Although their inherent wetness makes management difficult, wetlands have potential for greater forest production if soil-water relations can be improved. Development of management alternatives which will upgrade productivity yet conserve regional water supplies is dependent upon the improved hydrology of these soils. It is an area where there is a dearth of information.

Streamflow records from small bog watersheds in northern Minnesota show that as much as 80 percent of the total annual streamflow has occurred prior to June 1 in most years. Approximately two-thirds of the past few years' annual peak discharges have occurred during May. Nearly all of the high peak flows are associated with high water tables that normally occur in the bogs in the spring following snowmelt. During most spring seasons the bogs are saturated, and subsequent precipitation contributes directly to surface runoff. Contrary to popular beliefs, streamflow from areas having significant amounts of bog types is not particularly well regulated.

Improvement of southeast coastal plain forests through water management practices requires understanding of their water relations. Particular emphasis needs to be given to the amount of water lost through evapotranspiration in the various forest types at different seasons under differing moisture stresses. From this information guides can be developed to determine the amount and frequency of water excess to the requirements of wetland forests.

Study of water tupelo, a valuable timber species, in a swamp along the Santee River in South Carolina, showed that maximum diameter and height growth occurred where soil and site were poorly drained and subject to long periods of wetness. It also appeared that seepage into the swamp from adjacent upland areas provides important supplemental moisture for this water-loving species. With increasing intensive management of water levels in lowland swamps, close attention must be paid to their control if water tupelo is to be perpetuated on these sites.

On the other hand, large-scale drainage programs underway in other wetland forests are being evaluated to aid forest managers in determining the desirability of drainage to favor other species. Changes in soil productivity were assessed by measuring growth rates of pines before and after drainage on wet, sandy pinelands in northwest Florida. Comparison of observed increments with expected (based on pre-drainage performance) show that improved soil drainage has resulted in increased site productivity. Surveys have shown that, under certain conditions, increased site productivity for slash and loblolly pine by controlled drainage could almost double pulpwood yields from lands of this type in the southeastern coastal plain.

5. Public Law 480 Projects

a. Monographic revision of the genus Tamarix. The genus Tamarix, native to the Middle East, includes saltcedar, one of the most troublesome phreatophytes of Southwestern United States. Considerable study is being made of methods for controlling and replacing it with plant cover having a lower water requirement. To better understand the growth requirements of Tamarix as an aid to control, a research project in Israel under Public Law 480 is studying the taxonomic characteristics and occurrence of the several species. Material from herbaria throughout the world are being examined by the project staff, and representative specimens collected in the United States are included for identification. Observations of living plants have been made throughout Israel and Turkey. All pertinent literature has been gathered and card-indexed, and the generic delimitation is now under preparation. A revised monograph of the genus will be published as soon as all the data are assembled.

From the practical point of view, the main taxonomic characteristics used by the principal investigator for the subdivision of the genera are: shape and size of leaves, structure of the inflorescence, width of the racemes, size of sepals and petals, and number of stamens in the outer whorl of the androecium. Almost all species are well delimited, but some can be only tentatively named because of problems of synonomy.

b. Study of difference in effects of forest and other vegetative covers on water yield. Consumptive use of water by vegetation bears directly on the part of total precipitation that becomes streamflow. The increasing need for water in the United States and other parts of the world has focused attention on acquiring comparative information of the effects of vegetative types on total water supplies. In low rainfall areas the most economical use of land may involve planting to vegetative covers requiring small amounts of moisture. The Soil Erosion Research Station, Ruppin Institute of Agriculture, Nathanya, Israel, is studying moisture availability from bare lands and lands planted to pine forests, oak-chaparral, and grasses under a 5-year grant.

In this study three separate techniques of investigation will be compared and integreated to determine water losses from evapotranspiration or ground-water recharge, throughout the full hydrologic year. In addition to providing a better understanding of water transfer, the study will yield information as to the kinds of vegetation that can best be supported under low-rainfall conditions.

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B. FOREST RECREATION RESEARCH

Problem

Forest recreation continues to soar as a major use of the forest resource. The National Forests welcomed 5 million visitors in 1925, 16 million in 1940, and 150 million are expected this year. Other public and privately owned recreation lands are experiencing similar increases. Forest land managers need reliable methods for estimating and allocating the amount and type of recreation they must provide today and during the coming years. Much of the use is concentrated, many recreation sites are worn and depleted, and some recreation uses are not compatible with others. Administrators must know how to restore damaged sites, how to better plan and manage for recreation at new sites and in the surrounding forest areas, and how to coordinate recreation use with other forest resource uses, which in most areas are also accelerating. To meet this obligation, we are learning more about the physical and biological requirements of recreation areas and the management of their soils and vegetation. We are learning more about the people who go to the forests, woodlands, and wilderness areas for their outdoor recreation enjoyment. And, we are learning more about the impacts of recreation upon the economy and upon other forest resources in the area.

USDA and Cooperative Programs

Research at 8 of the 10 Forest Experiment Stations is underway toward answering these problems. Studies fall into three broad categories--those dealing with forest recreation use, those directed at the forest recreation environment, and those dealing with the economic aspects of forest recreation. Each Station is concentrating its studies on selected critical problems, often national or interregional in scope, rather than attempting a program of research embracing the broad spectrum of problems found in its geographical region. Most of the studies are in cooperation with other Federal, State, and educational institutions. Staffing varies according to the research emphasis, and currently 19 scientists from 7 different disciplines make up the professional staff.

A total of 21 professional man-years of effort was devoted to forest recreation research during the past year.

Progress--USDA and Cooperative Programs

1. Effect of recreation on forest environment

How does ground cover react to different intensities of camper use? In a Pennsylvania study, the close of the camping season revealed much less vegetative cover and a decline in the number of plant species. This is what one would expect, however, the losses were not steady. Campsites that averaged

one camper per day over the 100-day summer season averaged only 10 percent loss of cover. With heavier use, the loss was rapid. When use averaged two campers per site per day, ground cover loss soared to 60 percent. Several plants, such as wild strawberry, violets and mosses disappeared after very little use. Pathrush and Canada bluegrass, however, may have the resistant, compaction-tolerant attributes needed. These plants withstood heavy use remarkably well and invaded areas which were formerly occupied by less tolerant plants.

Arizona and Utah studies indicate that quaking aspen (Populus tremuloides) should be given serious consideration as a campground species. In areas of heavy camper use, many conifers disappeared, but aspen increased. Furthermore, aspen responded favorably to fertilization and irrigation. Treated trees were more vigorous and their growth rates increased 17 to 36 percent over the untreated control trees.

2. Forest recreation use

It is becoming increasingly evident that to develop recreation facilities, provide a satisfying array of recreation opportunities, and still maintain the land resource, forest land managers must have a much better understanding of recreation visitors, their preferences, and activities.

An Oregon study makes us consider some aspects of recreation behavior--perhaps obvious things most of us know but often disregard. Campers tend to group themselves into specific activity aggregations such as for fishing, nature study, swimming, and water skiing. Often the requirements of one aggregation are incompatible with that of another. Unplanned or forced intrusion of one activity on another can alter the complexion of use, demand on the site, level of satisfaction, and can often create antagonism toward the administrator. The nature study camper usually wants wide spacing and tranquility. The water skier seems to like company near his camp (particularly if the company is that of fellow skiers) and together the skiers may complain the camp's boat launching facilities are inadequate. The swimmers, fishing group and nature study group, on the other hand, think that large boats and water skiing should be prohibited because they can no longer enjoy the fishing, swimming, and quiet that once prevailed--and the forest manager who has provided a standard campground to serve all of these groups is still looking for a friend.

None of the 12 campgrounds studied was specifically planned for the activity to which it was host. A suggested though difficult solution would be to design campgrounds to meet specialized needs, publicizing this, and meeting the varied requirements of these diverse segments of the public by allocating the different campground types on a regional basis.

The need for allocation or zoning also applies to larger areas, and its application should effect greater user satisfaction, better distribution of use, the opportunity to provide for greater number of visitors, and at the same time help protect the forest land resource. A previously reported study in the Boundary Waters Canoe Area showed that wilderness has a different meaning to different visitors. To some their wilderness must be pristine; to others, their "wilderness" was not lost even with roads and heavy use. Zoning portions of the Boundary Waters Canoe Area for motorboats, while the core is set aside for canoeists, will soon become fact. Zoning is expected to distribute more users to areas now underused, and would allow for a use increase of about 60 percent over present use and still maintain a high degree of user satisfaction. Zoning alone, however, is not a final answer. Use has been steadily increasing at a rate of about 12 percent a year. By the year 2000 over 6 million people will be seeking solitude in the Boundary Waters Canoe Area unless numbers of visitors are regulated.

How does age or stage in the family life cycle affect forest recreation participation? Are elderly citizens and young families "locked out" by wilderness reservations? According to an Oregon study of 740 wilderness campers, easy-access campground campers, and campers who participated in a combination of easy-access and wilderness camping, the answer is "No." Most of the combination camping families were those in the early stages of the family lify cycle. Easy-access campers represented the middle and post-retirement stages, and wilderness campers were those with young children and just beginning their families, and young single adults. Very few persons over 65 years of age participated in any type of camping.

3. Economics of forest recreation

As our society becomes even more affluent and our mobility and leisure time further increases, opportunities for private outdoor recreation enterprises should improve. At present, however, a successful business is not assured. A study of 108 privately owned campgrounds in New Hampshire found that (1) only 10 percent of the campgrounds were full throughout the season; 35 percent were full on weekends, but often empty the rest of the week; the rest were one-half full or less most of the time; (2) seasonal attendance at 34 campgrounds was less than 100 camping parties per campground; average fees were $2.00 per party per night; average length of stay was two nights; and average gross camping fee income per campground was less than $400. Another study of 25 privately owned campgrounds in 5 States along the Ohio River showed that 85 percent of all campground visits were on weekends, and that occupancy averaged only 7 percent over the season.

Another Ohio study shows that privately owned, fee-charge farm woodland picnic enterprises are more apt to be successful if they are near large metropolitan areas and a combination of services and outdoor activities is provided. Most picnickers want more than just picnicking facilities. Income from one-third of the enterprises was not enough to cover operating expenses, and an even larger number did not compensate their owners for their labor, management, and interest on investment. Fee incomes to pay costs and compensate the owners were substantially better if (1) greater amounts were spent on advertising, (2) swimming facilities were provided, (3) more people lived within 30 miles of the enterprise, (4) more services and facilities were provided, such as playground equipment and leadership in outdoor activities, and (5) personal incomes in the area were greater.

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C. RANGE MANAGEMENT

Problem

Forage production on extensive areas of rangeland is far below potential and fails to meet the needs for livestock and game grazing. In many areas, particularly in the western mountains, watershed values have been seriously impaired by severe grazing. Management of these lands is often complicated by variable and droughty climate, highly erodible soils, and sensitive vegetation that cannot withstand close grazing use. Furthermore, livestock grazing must be coordinated with wildlife use and often with timber production. Improved management practices must be developed to allow sustained forage production in harmony with other uses and values.

Special phases of the range management problem are: (1) to determine growth characteristics and requirements of range vegetation, (2) to evaluate forage, classify range condition and trend, and develop better vegetation measurement techniques and range inventory procedures, (3) to develop optimum management systems to obtain maximum production and efficient use of forage on the various types of rangeland, (4) to determine effects of fire on vegetation and soils and to develop practical guides for its use in controlling undesirable plants and in increasing quantity and quality of forage production, and (5) to ascertain the ecological relations of rodents and other range pests as a basis for their control.

USDA and Cooperative Programs

This is a continuing, long-term program of both basic and applied research at numerous locations in the various range plant communities of the West, Midwest, and South in cooperation with State colleges, universities, and agricultural experiment stations; with the Smithsonian Institution, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Agricultural Research Service, numerous herbaria, private companies, and livestock associations or individual ranchers. In addition there are two PL-480 projects: germination of seeds of desert plants (Israel) and studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions (Spain).

The Forest Service scientific effort involved in this research totals approximately 47 professional man-years.

Progress- USDA and Cooperative Programs

1. Characteristics and Requirements of Range Plants

a. Ecology and physiology. On summer range in southern Montana, distribution and abundance of range vegetation is strongly influenced by exposure and soil depth. Sagebrush occurs mainly on south slopes while shrub-free herbaceous communities occur on north slopes. However, belts of sagebrush often extend into the forb-grass type on the north slopes, and shrub-free pockets of herbaceous vegetation occur within the sagebrush on south slopes. The sagebrush type occurs consistently on stonier, shallower soils than the forb-grass type, both on north and south slopes. Soil depth averages 2.0 feet in the forb-grass type and 1.1 feet in the

sagebrush type. Herbage production in the forb-grass type was almost double that of the sagebrush type, both on north and south slopes. Most herbaceous species were common to both types. Sticky geranium (Geranium viscosissimum), lupine (lupinus parviflorus), bigstem aster (Aster integrifolius), slender wheatgrass (Agropyron trachycaulum), and mountain brome (Bromus marginatus) accounted for most of the herbage production in both types. Such information is necessary for correct determination of site potential and consequently for classification of range condition.

Soils from high altitude sheep ranges in Wyoming vary widely in their potential for plant growth. Those derived from glacial till produced about 10 times as much herbage of desirable sedges under greenhouse conditions as those derived from volcanic breccia. Differences in productivity of the soils from glacial till and those from volcanic ash were even greater. Potential productivity of the mountain soils is an important consideration in how they should be managed for livestock and game range.

Studies in the central Oregon juniper zone have provided a realistic basis for management through the recognition of specific taxonomic vegetation-soil units. The current potential of these units for forage production is defined in terms of kinds and amounts of specific plant species. If serious deterioration has occurred and characteristic vegetational components are missing, the ecosystems can still be identified for management purposes on the basis of soil and topographic characteristics.

Ecological and physiological information on important forage plants is providing basic information for better range management. Tall bluebell (Mertensia arizonica var. leonardi), relished highly by sheep, is one of the dominant species on many ranges in the mountains of central and northern Utah. Life history studies have shown that basal buds form before snowmelt (mid to late May), flowering begins about 4 weeks after snowmelt, and mature seeds are shed 18-28 days after flowering. Seed germination ranged from 0-60 percent in the laboratory. About 40 percent of the seed planted in the field produced seedlings the following summer, but survival was low (1-3 percent). When tall bluebell is subjected to herbage removal and trampling, herbage yield declines approximately in proportion to amount of foliage removal. June clipping had the most severe influence. Trampling reduced yields in pure stands but not in plant mixtures.

Clipping studies have shown that part of the damage to bunchgrasses from burning results from foliage removal. Squirreltail (Sitanion hystrix) was damaged most by herbage removal prior to seed maturity, whereas needle-and-thread (Stipa comata), which does not become dormant, was seriously damaged by herbage removal during summer months after seed maturity. Clipping little bluestem (Andropogon scoparius), big bluestem (A. gerardi), and Indiangrass (Sorghastrum nutans) plants once a year for 3 consecutive years on glade ranges in the Missouri Ozarks reduced yields and vigor whether clipped each year in May, June, July, or August. Clipping after plant maturity in September and November increased plant yield and vigor.

Knowledge of seed germination and seedling establishment is fundamental to range revegetation. Work with fourwing saltbush (Atriplex canescens) seed in the laboratory disclosed the strong influence of temperature. Germination was substantially higher within the range of 40 degrees to 60 degrees F. than at temperatures of 70 degrees F. or higher. Also, dewinged seed was found to

germinate more rapidly than winged seed. Other advantages of dewinging are: (1) ease of handling, especially when the seed is drilled, (2) reduction in bulk, and (3) easier coverage with soil.

Under the PL-480 project in Israel, further information was obtained on the germination-regulating mechanisms of several species. An active phytochrome, inhibiting germination in Gymnarrhena micracantha, was found to be gradually inactivated by temperatures slightly higher than 40 degrees F. In the case of Hypocyamus desertorum, gibberelic acid induced germination between 59-86 degrees F. in the dark, but reduced germination at 59 degrees F. in light. For Artemisia monosperma all spectra of light (blue, green, red, and far-red) were equally effective in continuous and short periods of irradiation in effecting germination. For Hirschfeldia incana, germination level was determined by initial temperatures of seed exposure, and longer temperature intervals were required at suboptimal than at optimal temperatures. Length of temperature intervals for germination were not affected by moisture relations of the substrata.

Under greenhouse conditions in Colorado, seedlings of Idaho fescue (Festuca idahoensis) survived and developed equally well under both high and low levels of soil moisture. However, many Thurber fescue (Festuca thurberi) seedlings failed to survive at the low level. Evidently Thurber fescue seedlings are poor competitors or require more moisture for establishment than Idaho fescue seedlings.

In Arizona, measurements between 1940 and 1953 showed that pinyons, junipers, and shrubs increased in abundance on both grazed and ungrazed areas. In general, number of understory plants was inversely related to density of tree overstory. Herbage yields were from 600 pounds per acre where no trees were present to less than 100 pounds per acre where tree canopy occupied 60 percent of the area. Differences in herbage production under juniper trees ranged from none directly under the tree to 475 pounds per acre beyond the tree crown. Where shrubs of Arizona chaparral were killed by herbicides, the cover of all understory vegetation--perennial grasses, half-shrubs, and forbs--increased on quartzite-derived soils. On deep sandy soil derived from diabase, half-shrubs and forbs increased in cover and herbage production, but perennial grasses showed little if any response. Apparently sites for chaparral control must be carefully selected. Certain sites may not favor grass growth, and undesirable forbs and half-shrubs may become dominant following spraying.

2. Range Vegetation Evaluation

a. Forage value. Amount of crude protein furnished by grasslands after midseason in the Blue Mountains of Oregon is generally low, and percent protein remains below cattle requirements unless fall rains produce new growth of such species as Sandberg bluegrass and onespike danthonia. In some years inadequate protein levels last only 6 weeks on these summer ranges, and is not serious. However, in other years supplemental feeding would probably improve the efficiency of beef production.

On sagebrush-grass range in eastern Idaho, normally used in the spring and fall, sheep grazed during the summer months showed a high preference for grasses instead of forbs and shrubs. Grasses remain green later in the season and consequently are more palatable than the forbs, which are mostly dry by early July. Shrubs are most palatable and nutritious in the fall when both grasses and forbs are completely dry. A mixture of species is apparently essential for seasonlong use of this type of range.

Sherman big bluegrass (Poa ampla) continued to outproduce other seeded species at Manitou Experimental Forest in Colorado during 1963-64, despite rather severe drought. Average (6 years) beef production from this species, singly or in mixture, is now 88 pounds per acre. Average grazing capacity for big bluegrass is now 58 animal-unit days per acre, nearly twice as much as crested wheatgrass, intermediate wheatgrass, Russian wildrye, smooth brome, and other grasses, as found in an experiment to determine ways to extend the "green feed" period beyond that of native grasses.

b. Vegetation measurement and sampling. Grazed-plant guides were developed in the Southwest for estimating the utilization of blue grama (Bouteloua gracilis), Kentucky bluegrass (Poa pratensis), mountain muhly (Muhlenbergia montana), and Arizona fescue (Festuca arizonica). These guides, based on the relation between number of plants grazed and actual utilization by weight, are easy to use and give reasonably precise estimates of utilization up to about 45 percent.

In Montana a method was devised by which the volume of a cylindroid superimposed on a shrub crown can be converted to weight of herbage. The relation of herbage weight to crown volume varied between sites; however, by clipping 10 random plants it was possible to establish a reliable regression appropriate to the site under examination.

A new electronics instrument for measuring herbage yield, the heterodyne vegetation meter, was built and tested in California. The meter compares favorably with hand clipping in accuracy, but it is much faster. Plot yield of grasses and forbs can be estimated in 10 seconds with the meter, whereas clipping requires several minutes. Accuracy of the meter for shrubs is unknown. Further tests, particularly with shrubs, will be made during the coming year.

c. Condition and trend. A method of determining range condition using factors measured by the loop method was evaluated on ponderosa pine-bunchgrass range in Colorado. Range condition was classified by the relative production of desirable plants, desirability being based both on ecological status and forage values. Forage production is then estimated from a multiple regression equation based on loop hits and leaf length of mountain muhly. A chart is then developed to allow classification of range condition directly from loop-transect records and measurement of plant heights. The procedure is proposed as a rapid method that will have a factual background and for which the reliability can be determined.

3. Livestock Grazing Practices

a. Native ranges. On natural, unimproved annual-plant rangelands in California, yearlong continuous grazing at a moderate rate is proving superior to seasonal grazing for the maintenance of breeding cows. Under yearlong continuous grazing, young cows developed faster in body weight and were consistently heavier throughout all seasons of the year than those under repeated-seasonal and rotated-seasonal systems of grazing. Between ages of 3 and 6 years, cows on continuously grazed areas averaged 75-120 pounds heavier than cows on seasonally grazed areas. Differences in calf weights have been neither so striking nor consistent.

On a bunchgrass range in Oregon, calves in 1964 under light, medium, and excessive rates of stocking gained 126, 118, and 109 pounds, respectively; comparable cow-weights were +22, +7, and -12 pounds. Differences in cattle weight gains between deferred-rotation and seasonlong grazing were smaller than those due to rate of stocking; however, greater cattle weight gains were often associated with the seasonlong system.

On sagebrush-grass ranges in Idaho, heavy fall grazing by sheep is maintaining ranges in good condition and improving ranges that were in poor condition. Spring grazing, fall grazing, and complete protection have been compared since 1950. Heavy fall grazing (60 sheep days per acre) and complete protection have been equally effective in maintaining good range condition and in improving poor condition range. On good condition ranges, production of desirable forbs and grasses was maintained; on poor condition ranges, desirable forage species increased about 50 percent, and the undesirable sagebrush decreased about one-third. By contrast, heavy spring grazing (40 sheep days per acre) caused rapid deterioration of good-condition range; production of grasses and forbs decreased 50 percent and production of sagebrush increased 75 percent.

In southwestern Idaho, yearling ewes gained as much weight on predominantly cheatgrass range as on perennial bunchgrass range for a 6-weeks' season from April 1 to May 15. They generally lost weight (0.10 pound per head per day) during the first 2 weeks of the 6-week season, but gained well during the second and third 2-week periods (0.49 and 0.58 pound per head per day, respectively). Heavy stocking of cheatgrass ranges for 5 years has not adversely affected daily gains of sheep nor grazing capacity. On the other hand, gains of yearling cattle on cheatgrass ranges during the fall were greatly reduced by heavy stocking rates.

Under continuous protection from livestock grazing, black sagebrush (Artemisia nova) now comprises 63 percent of the total shrub production, compared to 36 percent in 1947 and only 5 percent in 1937, on a salt-desert shrub range in western Utah. Black sagebrush, the most desirable species on this winter range, now yields 75 percent of the usable browse for sheep. Similar production can be attained on properly grazed areas as well as with complete protection.

In a 12-year study on longleaf pine-bluestem range in Louisiana, herbage utilization averaged 67 percent under heavy grazing and 46 percent under moderate. Grass yields averaged 3,350 pounds per acre under heavy grazing, 3,240 pounds under moderate grazing, and 2,650 pounds with no grazing. During the period of study, grass cover declined under all grazing intensities, but it decreased most on ungrazed range, probably because of the buildup and smothering effect of litter or "rough." Greatest losses were in slender bluestem (Andropogon tener). Pinehill bluestem (A. divergens) increased on ungrazed range, decreased on heavily grazed areas, and remained about constant with moderate use. Carpetgrass (Axonopus affinis), an invading but desirable species, increased greatly on heavily grazed range. Moderate stocking stimulated production as much as heavy grazing, without the drastic changes in vegetation, and proved less damaging to pine regeneration and soil conditions.

Better management, consisting of alternate-year deferment of grazing during the growing season combined with proper stocking rate, has allowed rapid increases in grazing capacity of semidesert range in Arizona. Historically, these arid ranges have been grazed yearlong, forage production varies greatly from year to year and

is generally low. In grazing experiments, an increase from 13 animal units per section in 1954 to 21 animal units in 1961 was realized by improved management. This is a 62 percent increase in grazing capacity in 7 years. Where mesquite was also controlled, grazing capacity increased 170 percent during the same 7-year period.

When cattle were allowed free choice, their pattern of grazing Missouri ranges varied with the season. In spring they grazed old fields and open glades; in summer they grazed mostly in the woods; and in fall they preferred partly closed glades. Protein deficiencies normally associated with these bluestem ranges were alleviated by high consumption of forbs and shrubs during late summer and fall, but no adequate source of phosphorus was available after June. Time spent in grazing was inversely related to temperature and humidity. Thus, on hot, humid days animals often eat inadequate amounts of forage.

b. Improved ranges. On crested wheatgrass range in Utah, the heaviest intensity of cattle grazing (80 percent utilization) initially produced the highest gains per acre, but animal production soon declined. During the last 5 years of the study, highest gains were obtained under intermediate stocking (65 percent utilization). Heavy grazing also reduced grass yields and accelerated invasion of big sagebrush, an undesirable shrub that competes with grass for the limited moisture supply. Apparently crested wheatgrass should not be utilized more than about 65 percent during the spring growing season.

Grazing by sheep in late fall shows promise for controlling invasion of big sagebrush into stands of crested wheatgrass, if grazing is started before brush stands become dense (not more than three or four plants per 100 square feet). Big sagebrush declined about 20 percent between the second and third year of late fall grazing by sheep; in contrast it increased more than 50 percent under early spring grazing by cattle.

Brushy Ozark ranges can be improved by aerial spraying with 2,4,5-T, seeding with introduced or native forage plants and, in the case of introduced species, by fertilizing. Reducing the hardwood overstory with 2,4,5-T is not enough; seeding of forage plants must follow because desirable native species are usually too scarce to regenerate. Three years after spraying and seeding, forage production per acre increased from less than 50 pounds to about 1,500 with seeded native grasses and to 1,100 pounds with a tall fescue-lespedeza mixture. Application of 320 pounds of 8-24-8 fertilizer per acre to the fescue-lespedeza mixture increased production threefold. Production of native grasses was not increased by fertilization.

4. Burning for Range Improvement

In Florida, prescribed burning was tested as a means of increasing forage production and controlling undesirable shrubs. Ranges burned in March or May produced two and four times respectively more forage 2 months after the fire than those burned in October, November, or January. Wire-grass (Aristida stricta) seeded profusely in the fall after a May burn, but produced few seed stalks when burned at other times of the year. Numbers of stems of gallberry (Ilex glabra) increased following initial burns in January, April, June, August, or October and then remained fairly stable through two additional burns, regardless of the month of burning. Apparently, fire will not achieve permanent control of gallberry.

Rotation burning is practical for improving forage quality on forest ranges of Louisiana. The system consists of dividing the range into three subunits and burning one each year in rotation. Cattle concentrate on newly burned range. During the first year after prescribed burning, they utilized 78 percent of the herbage; utilization dropped to 31 percent in the second year and to 18 percent in the third. The net effect of rotation burning on vegetation composition was beneficial. Fire materially reduced weedy grasses and scrub hardwoods. On timbered range it removed accumulated pine litter, which seriously impairs herbage production. Cows nursing calves gained 57 pounds on burned ranges between April and August, but lost weight on the unburned range.

Development and maintenance of upland tall-grass prairies in the Central States is improved by burning. Higher soil temperatures on spring-burned areas resulted in a 1- to 2-week earlier initiation of plant growth. About 80 percent of total foliage yield was produced by July 1 on burned ranges, compared to only 50 percent production at this time on unburned areas. Also, total plant production was much greater on burned than unburned areas. Interval between burns greatly influenced plant composition. On areas burned annually, forbs composed about 12 percent of the total yield; on areas burned biennially, 25 percent; on areas burned every fifth year, 41 percent; and on unburned areas, 50 percent. With 3-5 years of protection following burning, plant composition approached that of the unburned control areas. These results indicate that annual or biennial burning in this forage type will maintain the most desirable plant composition.

In the chaparral of central Arizona, shrubs, mainly shrub live oak (Quercus turbinella), regained dominance within 6 years after burning. Forb production reached a peak during the second and third growing seasons after the fire, then declined rapidly. Buildup of grasses was slower. By the sixth year after burning, cover of all herbaceous plants was declining. At best, burning offers only temporary conversion from chaparral to grass.

5. Range Pest Influence and Control

An eruption of voles (Microtus spp.) in southwestern Montana in 1962-64 during the winter months resulted in bark stripping and stem girdling of several species of valuable shrubs including bitterbrush, mountain-mahogany, serviceberry, and choke-cherry. Big sagebrush (Artemisia tridentata), usually of little value to livestock but an important plant on winter game range, was most severely damaged with up to 84 percent of the plants killed on several hundred acres in three counties. This outbreak demonstrates the impact that small, rather unobtrusive rodents can have upon stands of native shrubs.

In southwest Idaho, a narrow-winged thrip (Frankliniella occidentalis), a gall midge (Phytophaga spp.), a moth (Filitima spp.), and a stink bug (Chlorochroa sayi) destroyed about one-third of the potential seed crop of bitterbrush in the year of study. A sucking insect, probably Psylla spp., is suspected as cause of additional damage to seed. Also, feeding by the Say stink bug (Chlorochroa sayi) blackens and shrivels the ripening seed and renders it nongerminable.

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D. WILDLIFE HABITAT MANAGEMENT

Problem

Wildlife habitat, by supplying food, cover, and water, is the key to optimum game and fish production. Management of habitat is complex. Each species of animal has rather specific habitat requirements that must be balanced with production of water, timber, and forage for livestock. Demands for all uses of forest and related rangelands are increasing, and serious situations have arisen, often with severe impacts on game and fish habitats. Consequently, wildlife habitat research is needed to develop effective and harmonious management practices for the various vegetation types.

Specific phases of the problem are: (1) to devise methods for restoration of deteriorated habitats or for improvement of those naturally unproductive; (2) to develop and evaluate management systems through studies of the nature and degree of competition between wildlife and livestock, effects of timber production and cutting practices on forage for wildlife, and reciprocal effects of forage production and grazing use on timber reproduction; and (3) to determine the effects of land use on fish habitat and to develop ways to improve fish habitat and food supplies by such means as regulating shade and water temperatures, manipulating riparian vegetation, and stabilization of streambanks.

USDA and Cooperative Programs

This is a continuing, long-term program of both applied and basic research at numerous locations in the various plant-animal communities throughout the United States. It involves interrelations of wildlife and livestock, and integration of timber and forage values to allow optimum production and utilization of each. Studies are conducted in cooperation with various State and Federal agencies such as fish and game departments, agricultural experiment stations, Fish and Wildlife Service, Soil Conservation Service, Agricultural Research Service, Bureau of Land Management, and in some instances with sportsmen associations, private companies, and individuals. In addition there is a PL-480 project concerned with quantity, quality, and seasonal variation of food resources available to red deer (Poland).

The Forest Service scientific effort involved in this research totals approximately 29 man-years.

Progress--USDA and Cooperative Programs

1. Wildlife Habitat Improvement

Seed production studies of adaptable game forage plants for winter range are now being undertaken in central Utah. Fourwing saltbush (Atriplex canescens) provides an example of progress on two favorable sites. On an irrigated area, plants of fourwing saltbush from seeds of the highest yielding source (New Mexico) produced 2.4 times more herbage than those from the lowest yielding source (Nevada). On a non-irrigated area, yields from New Mexico and Nevada sources were nearly equal, and plants from the local seed source (Ephraim) produced highest yields. Apparently much progress will be possible through selection of superior strains of such species.

Fire sprouts of three shrubs in Arizona chaparral--shrub live oak (Quercus turbinella), birchleaf mountain-mahogany (Cercocarpus betuloides), and Wright silktassel (Garrya wrightii)--reached highest moisture, crude protein, and phosphorus values during early spring. Nutritive trends then declined gradually except for slight increases in response to summer rains. Heaviest use of fire sprouts by deer was made during the late spring growth period when herbaceous vegetation was mostly dry. Mountain-mahogany was preferred. During the summer growth period, there was light use of Wright silktassel and mountain-mahogany; shrub live oak was practically ingnored. Preference seemed to be associated with high moisture and crude protein content, low crude fiber values, and comparatively wide calcium-phosphorus ratios.

A single aerial spraying of Ozark woodlands with 2,4,5-T killed more than 70 percent of the low-quality hardwood trees. Grass yields were greatly increased the first few years after spraying but declined as browse growth increased. Yields of forbs preferred by deer were little affected by spraying. The yields of preferred deer browse plants, initially reduced by spraying, soon recovered to greatly exceed those on unsprayed woodland. If deer habitat is the main consideration, spraying should be less frequent than 8-year intervals and in alternate strips or small blocks.

In North Carolina white-tailed deer utilized clovers, when available, more heavily than grasses. Clover use was heaviest during the spring and summer. In late summer, when consumption of clovers was nearly complete, use of grasses began and increased throughout fall and winter. Monthly consumption of clover averaged about 350 pounds per acre (dry weight), and monthly consumption of grass, about 100 pounds per acre. Seeding small openings in the forests to clovers and grasses offers an effective means of improving deer habitat.

Intermediate cuttings to increase deer browse on the Allegheny National Forest in northern hardwood stands of pole-timber size have been successful. All stems except the future crop trees were cut during the winter season. An abundance of new browse was thereby made available to deer in the tops of the felled trees in winter and in stump sprouts the following spring. These cuttings released understory species and allowed a tenfold increase in browse production. Cutting blocks were about 10 acres in size, and were distributed at approximately one-half mile intervals.

2. Integration of Wildlife, Livestock, and Timber Production

Clearcutting lodgepole pine in the Rocky Mountains encouraged abundant forage production for game during the time a new timber stand was developing. A variable mixture of understory grasses, sedges, forbs, and low shrubs resulted from clearcutting. Seedbed conditions resulting from logging and slash piling did not affect production of sedges or forbs, but did affect production of grasses and shrubs. Shrubs were more abundant on undisturbed areas; production of grasses was greater on skidroads or burned and scarified areas.

and

Many forests in northern Idaho have been modified considerably by fire/logging. These activities have produced important changes in understory game food plants. Tall-growing shrubs are most abundant on sites that are broadcast-burned after logging; primary shrubs are likely to be scouler willow (Salix scouleriana), myrtle pachistima (Pachistima myrsinites), blueberry (Vaccinium spp.), and western thimbleberry (Rubus parviflorus). Also, redstem ceanothus (Ceanothus sanguineus),

snowbrush ceanothus (C. velutinus), bittercherry (Prunus emarginata), sitka alder (Alnus sinuata), and spinyleaf spirea (Spiraea lucida) are more abundant on burned areas than on unburned areas. Abundance of tall and intermediate-height shrubs is inversely related to density of tree overstory. Logging and slash disposal methods, then, are important tools for increasing game food and cover plants.

In Missouri, a great variety and density of wildlife fruit-producing species were found in bottom-land hardwoods. Dogwood (Cornus florida), sassafras (Sassafras albidum), fragrant sumac (Rhus aromatica), and dwarf sumac (R. copallina) were the most abundant fruiting species. Seventeen other species also produced fruits, but were of minor importance. Abundance and fruiting were increased as crown cover of overstory trees was reduced. The abundance of such fruiting species in the bottom-land hardwoods type is one of the principal reasons for its excellence as wildlife habitat.

Three years after extensive heavy selection cutting of mountain hardwoods in North Carolina, tree seedlings made up about 80 percent of the regeneration, yet deer preferred sprouts which grew on the old stumps. Approximately 60 percent of the sprouts were grazed as compared to 10 percent of the seedlings. Although the deer population is fairly high in this area, adequate forest regeneration is apparently assured.

Sampling methods using 1 inch depth soil cores for determining amounts and kinds of ground seed supplies for bobwhites were developed for relatively large wild-land areas. Differences can be detected with sufficient sampling precision to assess treatment effects in controlled experiments, pilot tests, and field demonstrations. Major source of variation was between locations of composite samples. Any unbiased system of distributing composite samples over the sampling area is acceptable. The method permits accurate determinations of ground seed supplies of value to bobwhites.

In red pine plantations in lower Michigan, overstory thinning increased browse production. However, the response was closely related to past use of the land. In plantations on land previously cultivated, browse production was extremely low, and thinning had little effect. In other plantations where understory plants were previously abundant, thinning greatly increased browse. In general, thinning to a residual basal area of 60 sq. ft. per acre (in stems 8-12 in. dbh) was much more satisfactory from the standpoint of increasing browse than thinning to a higher residual basal area as is commonly practiced.

Preliminary findings from a study in Colorado indicate that use of sagebrush habitat by deer, elk, and sage grouse varies with height of sagebrush and steepness of slope. Deer and elk use was concentrated in sagebrush shorter than 18 inches and on slopes of 30-40 percent. Sage grouse, however, made most use of areas on gentle slopes covered with tall sagebrush. During the spring, sharp-tailed grouse in South Dakota were found most commonly in tall grass communities characterized by green needlegrass (Stipa viridula) and western wheatgrass (Agropyron smithii). In fall they were most common in grain stubble and in fields of corn and alfalfa. Determination of preferred habitats of these game species is a necessary step in creating conditions for optimum production.

In pinyon-juniper habitat of southwestern New Mexico, elk and deer were found to prefer similar but specific sites. Heaviest use was on northeast exposures.

Lightest use was on level sites. Slopes in excess of 15 percent were used as heavily as gentler topography. In general, habitat use was related to abundance of birchleaf mountain-mahogany and Wright silktassel. Findings suggest that livestock range improvement and deer and elk habitat preservation can be coordinated by confining clearing of pinyon pine and juniper to slopes of less that 15 percent and leaving existing cover on northeastern exposures. Thinning of relatively dense stands of trees may improve elk and deer habitat, especially where palatable shrubs are present in the understory.

In Utah, vegetation type had a major effect on distribution of grazing use by deer and cattle, but to lesser degree by elk. For example in six different vegetation types deer use varied from 0.7 to 6.4 days per acre, and cattle from 1.3 to 16.2, whereas elk use varied only from 1.7 to 3.9. Mixed-shrub habitat was first choice for both deer and elk, followed by aspen and oak habitats. The grass-forb type was most preferred by cattle, but least by deer and elk. Steepness of slopes was another important factor affecting animal distribution on summer range, particularly of cattle. Over half of the total deer use, and 27 percent of the total elk use was on slopes in excess of 30 percent, whereas most of the cattle use (83 percent) was on more gentle slopes. Apparently competition is particularly light between deer and cattle.

In Oregon the diet of big-game animals reflected the marked seasonal changes that occurred in availability of palatable forage. In a complex of grassland, open timber, and dense timber, grassland produced the most forage and received heaviest use during the spring. Common camas (Camassia quamash) and bicolor biscuitroot (Lomatium leptocarpum) contributed the most forage. As these succulent spring forbs matured, big game shifted their feeding to grasses and shrubs in the forest habitats. Open forest was used most in summer, with elk sedge (Carex geyeri), arnica (Arnica cordifolia), and common snowberry (Symphoricarpos albus) providing most of the forage. In dense forest, whortleberries (Vaccinium spp.) were the preferred species.

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III. FOREST PROTECTION RESEARCH

A. FOREST FIRE

Problem

Forest fires affect every phase of national programs for the protection and management of forest resources. Wildfires damage timber, watersheds, scenic beauty, recreation areas, rangelands and wildlife. They often take a toll in human lives, threaten the safety of people in forest areas and metropolitan communities, and destroy buildings, utility lines and property values.

More than 100,000 forest fires occur annually on the 822 million acres of forest lands requiring protection in the United States. In 1963, more than 164,000 forest fires occurred; the greatest outbreak of forest fires since 1954. These fires burned more than 7,100,000 acres.

The annual direct costs to private, State and Federal agencies for control of wildfires is estimated at $150 million. The total amount of damage and economic loss from forest fires cannot be expressed adequately in dollars. The suppression costs and damages on a single disastrous forest fire in 1964 was estimated at $23 million.

The forest fire problem is big. It will continue to grow. Increased demands will occur for all forest resources. A predicted increase of the U. S. population to more than 300 million people in the next 30 years means an escalation of already complex forest fire problems. More people will require more of all the things that come from forests -- wood, water, wildlife, forage, scenic beauty and outdoor recreation. More people in the woods means more exposure to human sources of fire. More cities expanding into forest areas means new and more difficult problems in preventing and suppressing fires. Every aspect of a look ahead in forestry plainly indicates that the Nation must strengthen its ability to control forest fires.

The experience of more than half a century of organized forest fire fighting plus the results of fire research efforts organized for a much shorter period have laid the foundations for present forest fire control programs. Forest fire control involves a variety of techniques. These include reducing the flammability of forest fuels, measures to prevent fires started by people or machines, prompt detection of fires, and fast, powerful methods to suppress fires and minimize their damage. Intensive forestry involves the timely and judicious use of prescribed fires as a tool in the management of forest resources. In addition the fire consequences of forest management decisions and operations must be evaluated. To meet the stringent forest protection and management requirements of the future, methods must be developed to do all of the fire control jobs better and to grow forests less susceptible to fire. Totally new and more efficient methods must be found. Achievement of these objectives must come primarily from a strong program of forest fire research.

An important aspect of present day forest fire research activity is the unparalleled opportunity that exists for progress. Never before has there been more promise for developing new scientific approaches to the problems of protecting forests from fires. Advances in the sciences of physics, chemistry, meteorology, mathematics, engineering and forestry can all contribute measurably to progress in forest fire research. Space age technology in such areas as remote sensing, electronic systems, combustion

physics, and atmospheric sciences all provide new inputs to the development of more effective fire technology.

USDA and Cooperative Programs

The national program of forest fire research is performed by the Forest Service in cooperation with private, State and Federal agencies and universities. A major part of the research is performed at three Forest Fire Laboratories located at Riverside, California; Missoula, Montana; and Macon, Georgia - equipped with special facilities and manned by an interdisciplinary staff.

Forest Fire Research projects are also currently headquartered at Fairbanks, Alaska; Portland, Oregon; Berkeley, California; Flagstaff, Arizona; St. Paul, Minnesota; Columbia, Missouri; and Alexandria, Louisiana. These projects are closely associated with programs at the Forest Fire Laboratories. They strengthen both national and regional programs through utilization of facilities and cooperative assistance available at these locations and the surrounding forest regions.

Federal agencies cooperating in the forest fire research program include the U. S. Weather Bureau, National Park Service, Bureau of Land Management, National Science Foundation, and National Bureau of Standards. Much of the research has strong national defense aspects. Department of Defense agencies and departments cooperating in the program include Office of Civilian Defense, Advanced Research Projects Agency, Army Electronics Command, U. S. Air Force, and U. S. Navy. Several universities and state forestry departments also provide manpower, study areas and specialized equipment. In addition, the states of California, Georgia and Missouri make direct financial contributions to the fire research program.

In fiscal year 1965 forest fire research occupied 57 professional man-years of in-house effort. In addition, 3 1/2 professional man-years we financed by forest service funds for forest fire research by universities and other research institutions. This domestic program was supplemented by PL 480 funds in 2 countries totaling 57,570 U. S. dollars equivalent.

Progress - USDA and Cooperative Programs

1. Weather and Fire Behavior

a. Fire Physics. Work on the combustion of pine needle fuel beds in still air at Missoula has progressed to the point where a generalized mathematical model of the process is possible. Preliminary trials indicate that the model correctly predicts rates of spread regardless of variations in species, fuel loading, compactness and moisture content.

Wind tunnel tests at Macon have been used to investigate the mechanics of wind-driven fires. During the course of these experiments it was found that, even for low wind speeds, the lower layers of the flame front were nearly horizontal and that the horizontal velocity of the hot gases was greater than the speed of the ambient wind. This horizontal flame jet appears to be one of the major processes controlling the spread of wind-driven fires.

Studies of fires in wood cribs confirm the earlier California conclusion that radiation from flames is not a significant factor in determining rate of fire spread. Even when flames were completely quenched by carbon dioxide jets above the fuel bed, little or no decrease in rate of spread was noted.

b. Fuel Moisture. Progress in fuels research at Missoula indicates that we can now predict when the moisture content balance will be tipped suddenly toward a highly flammable condition. Cheatgrass will become a highly hazardous fuel 10-14 days following its stage of vivid purple coloration. Guidelines are being prepared for fire control agencies showing how to evaluate the drying rates and flammability of this important fuel which is found in abundance on several million acres in the west.

Fuels research is also showing how ignition takes place in forest fuels at specified moisture contents. Results indicate a spontaneous ignition temperature of 425° C. in ponderosa pine needles with a 7 percent moisture content. At this same moisture content pilot ignition occurs with temperatures as low as 270° C.

One of the puzzling features of Alaskan forest fires has been explained by the results of a study of moisture variations in Alaskan lichens and mosses. Large forest fires often occur in Alaska during periods of high rainfall that would be considered "safe" anywhere else in the United States. This study showed that lichen-moss fuels are extremely fast in reacting to changes in atmospheric humidity, and that they will burn well whenever humidity drops below 40 percent, regardless of the amount and recency of rainfall.

At the opposite climatic extreme, research in Arizona has demonstrated that the oil content of chaparral changes appreciably with the moisture content of the foliage. This work has practical implications in predicting chaparral flammability and further investigations are planned.

c. Meteorology. A Defense Department sponsored study of critical fire weather patterns of the United States has been completed at the Riverside laboratory. The final report represents a significant milestone in forest fire meteorology and will be used by fire weather forecasters for many years to come.

The cooperative Cascades Fire-Weather Project in the Pacific Northwest has continued to develop new instrumentation and techniques for the types of intensive climatic surveys needed to understand the complex fire-weather patterns of mountain areas.

In a much smaller way, a study at the Central States Forest Experiment Station will also be of significant help to fire and weather people. In order to do a good job of preparing special weather forecasts for large fires, the forecaster must have wind measurements taken at the fire scene. These measurements are usually taken with small hand-held instruments that give accurate readings of gust speeds, but not of average speeds. The Central States project has prepared a table to convert fireline wind readings to Weather Bureau standards. The result should be more consistent and accurate local forecasts.

d. Fire and Environment. A continuing program in California is investigating the characteristics of mass fires by intensive measurements on full-scale field tests. Last year plots up to 5 acres in size containing up to 180 tons of fuel were burned. Results of last year's tests showed: (a) air flow patterns that create eddies can result in fire whirlwinds when fire is present; (b) the lower part of the convection column consists of a series of small columns that merge well above the combustion zone; (c) air flow for combustion in large fire may come from a relatively deep layer around and above the fire; (d) flame temperatures are much higher than in small experimental or laboratory fires; and (e) toxic gases occur within, and adjacent to, the fire with no significant concentration in the area between fires when fires are spaced 115 feet or more apart. This program has developed a general

understanding of the mass fire problem with significant implications to national defense planning. The results are being integrated with appropriate Department Defense Agencies. Fire research personnel cooperated in preparing an Office of Civil Defense planning manual and in presentation of similar material to a subcommittee of the North Atlantic Treaty Organization.

2. Fire Prevention

a. Man-caused fires. Previous studies in cooperation with the University of Southern California have developed criteria for designing effective roadside signs for fire prevention. This year we put the theories to the test and compared 5 commonly used fire prevention signs with 5 signs designed by the research project staff. The results justified the theories. The set of new signs reduce the number of persons failing to notice signs by half. People were also more likely to remember that the signs were concerned with fire prevention. Seventy-six percent of respondents exposed to the new signs could recall one as outstanding, in contrast to only 46 percent of those exposed to the old signs.

In 1963 a survey was made of fire-related attitudes and characteristics of forest residents in three northern Mississippi counties where the Yazoo-Little Tallahatchie Flood Prevention Project has an intensive forestry program, including tree-planting and intensive protection of plantations. About 77 percent of the 751 respondents had generally favorable attitudes toward forestry, conservation, and fire protection. The 10 percent who appeared definitely unfavorable tended to be older, less educated, less involved in community affairs, and poorer with respect to modern conveniences and communication items. However, a disturbing number of large farm operators held unfavorable opinions on forestry. There was indication that better markets for forest products would improve the general attitude. Despite the intensive forestry program, the Y-LT Area Forester was much less well-known than the County Agent.

A survey of 121 residents (nearly 100 percent) within a national forest ranger district in Louisiana showed a reversal in attitude toward the U. S. Forest Service from 70 percent unfavorable in 1941 to about that percentage favorable in 1963. More non-owners than owners of cattle favored regulation of burning, but more owners professed to feel that periodic burning was no longer necessary. In general, re spondents gave the Forest Ranger a prestige rating in the middle of the comparative scale, below minister, school principal, and teacher, but above county agent, forestry worker, and police juror (county commissioner). Those with a poor opinion of the Ranger and his work tended to favor periodic burning, disapprove of legal restrictions on burning, and cite revenge as the motive for a large proportion of forest fires.

In the Northeast, a study of fire causes in Maine showed that: (1) approximately 90 percent of forest fires in Maine are man-caused and thus subject to influence by prevention programs; (2) children under 12 are an important element in the forest fire picture in Maine, accounting for between 20 and 25 percent of all fires that could be tied to an individual; (3) of these same fires, 97 percent result from the activities of State residents, with 85 percent being caused by resident of the town within which the fire occurred.

And in Montana, a small but definitive study gave a conclusive answer to a question that has long bothered foresters: Can old, discarded cans and bottles start forest fires? Yes, light fuels can be ignited immediately by refraction of bright sunlight through glass jugs containing liquid or by reflection from concave portions of metal

cans. Measurements of light concentration indicate that many common containers can start forest fires.

b. Lightning-caused fires. Project Skyfire at Missoula continues to uncover new and important information about basic lightning processes and possibilities for lightning modification. There are at least two distinctive types of lightning strokes, and it appears that only one may be capable of starting fires. If this is true, we may be able to prevent fires by merely altering the type of lightning discharge. This may be easier to accomplish than actually suppressing the number of lightning strikes. However, tree damage is caused by rapid vaporization of the moisture within the tree itself. Very little of the energy available in a lightning discharge is required to vaporize tree moisture and to produce gas pressure sufficient to cause structural damage. Thus, any cloud-to-ground discharge is capable of severely damaging a tree.

3. Fire Control Systems and Methods.

a. Detection. The evaluation of airborne infrared scanners for detection of incipient forest fires is the mission of a continuing and exacting project at the Missoula laboratory. To be economically competitive with the existing lookout system, infrared aircraft must be able to detect and accurately locate small fires within an 8-10 mile swath during sustained high speed flight. Improvements in equipment and techniques were made during the past year to bring this goal a step closer, but further research will be necessary to develop an operational system.

b. Presuppression. Operations research studies in cooperation with the University of California at Berkeley have developed four analytical models for determining the best size and strength of initial attack effort. One of these models uses a multistage, dyamic programming technique that has never before been utilized to study problems of this kind.

Investigations into the adoption of fire resistant species for use on California fuelbreaks hit an unexpected snag when 3 of the 8 species tested proved irresistible to rabbits. Mediterranean saltbush, which had been considered very promising, was completely wiped out within 3 weeks of planting. The fuelbreak program did achieve one marked success last year in developing a technique for killing scrub oak, a species heretofore resistant to anything available. A partially soluble soil sterilant, applied at a rate of 1.8 ounces or better in a ring around the sprouting plant crown will do the job.

The use of fire retardant chemicals for season long fireproofing of roadside vegetation remains an unsolved problem. Formulations were developed that could withstand up to 1/4 inch of rain, but under further washing or repeated applications would not remain effective. The problem seems to be a basic one, since the fire retardant effectiveness of the salts appears to be directly proportional to their solubility. Thus an effective mixture washes off and a long lasting coating won't retard fire.

c. Suppression. The Northern Forest Fire Laboratory has completed a very important study of short-term fire retardants and their relative effectiveness under various conditions. They found that the retardants dry according to temperature-humidity-wind conditions and the amount of retardant applied to the fuel bed. There is no practical difference in the drying rates between the retardants commonly used in forest fire suppression. Rate of spread of fire in a fuel bed treated with a short-term retardant is dependent upon the moisture present, and is effective only as long as the equivalent of 20 percent or greater fuel moisture content prevails;

below that, the retardant fails. The results of this program have immediate applicability for helping fire control personnel decide when and where to use various retardant formulations.

A companion project studying long term retardants at the Southern Forest Fire Laboratory is not yet completed. A reproducible static test for rating fire retardant chemicals has been devised. Test values indicate that dry phosphate salt (DAP) is four to six times more effective in retarding fires than dry borate. Dry attapulgus clay showed some retardant properties of its own, but when used as a thickener with DAP, the effectiveness of the salt was cut in half. About 1-1/2 units of ammonium sulfate were required to do the work of one DAP unit. Solutions prepared from liquid phosphate concentrations were found to be almost as good as those prepared from the dry salt.

A new retardant was tested in California. This gel-type fire retardant with an extremely high viscosity producing ability has shown much promise both in the laboratory and field. The chemical consists of small particles that do not dissolve but swell about 300 times their initial size when wetted. About 2 pounds per 100 gallons is sufficient to produce a thick stable gel that will not spoil. After laboratory and field tests we put the material into operational use, and it was used widely from helitankers during 1964. The material has proven so successful that it will probably be used in virtually all helitanker operations during 1965.

Despite a Japanese report that wire screens successfully stopped fires in light fuels, tests in California showed that meshes of 16 guage wire screen from 1/8-inch to one inch and 3 feet in height did not stop ground fires in grass, bearclover, pine needles or chaparral.

Infrared mapping of forest fires is now nearing development as an operational tool for forest protection agencies. The airborne infrared mapper developed at Missoula, Montana was used on the disasterous Coyote Fire at Santa Barbara as an integral part of the fire intelligence operation. Infrared imagery often provided the only information on the fires exact location, and men and equipment were dispatched on the basis of this imagery. Infrared mapping was also tested on 16 other large fires in 1964.

4. Fire Effects and Use.

a. Thermal Effects of Fire. A repeatable, controlled technique has been developed at Macon for studying the heating of tree trunks in forest fires without burning sizable plots. Exposure of lower trunks of trees to surface fires can be simulated by burning an oil-soaked wick wrapped around the trunk near the ground. External and internal tree temperatures on both windward and leeward sides are comparable to those in natural-fuel burns, and the wick provides better fuel control, ease of replication, economy of labor, low risk of fire escape, and conservation of trees.

b. Prescribed Fire. The Southern Forest Fire Laboratory is continuing its research into palmetto control. One-year measurements on palmetto after combination treatments using prescribed backfires and "mist" applied 2, 4, 5-T at rates of 2 and 4 pounds acid equivalent per acre in water and non-phytotoxic oil, showed little success in control. The best treatment (13 percent plant kill) consisted of a spray applied in late July followed by a burn in early October. Plant population increases, however, amounted to 34 percent as a result of sprouting.

c. Techniques of Burning. Asphalt or wax coatings can be used to extend the season for successful slash burning, but they are somewhat expensive according to a recent California study. Properly applied after slash was thoroughly dry, good burns were possible in the winter after as much as 8 inches of rain had fallen. The technique is expensive since the coatings must be applied after the slash has had time to dry. Because treatment cannot be combined with either the logging or the burning operation, labor costs are high.

Slash burning can be extended later into the summer season too. Field tests on eight Douglas fire slash fires show that ammonium phosphate fire retardants can be very helpful in controlling slash fires. Retardant was sprayed on the adjacent vegetation outside control lines that would be subject to ignition by spotting or radiation. In addition, some areas within the block itself were sprayed in order to reduce rate and spread and fire intensity. In general, spot fires in treated areas were about 1/3 of that in untreated areas. Rate of spread was reduced to about 1/10 that in untreated slash.

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B. FOREST INSECTS

Problem

Research in forest entomology is currently undergoing dramatic changes in keeping with modern changes in science, economy and sociology. Our forests are becoming more valuable and their uses more numerous. While forest areas are diminishing in size due to urbanization, highways, airports, and similar land demanding changes, pressures for timber, water, wildlife, recreation, and esthetics are becoming greater. This will mean more intensive forest management and more intensive and complete protection in the future. The losses we have experienced in the past will no longer be tolerated.

Thus, greater emphasis will be placed on prevention of insect outbreaks or early detection and immediate application of control measures compatible with the forest environment and man's use of this resource. This can only be attained by a better understanding of the biology and ecology of the pest insects and the interrelationships between them and their environment. It will mean development of new methods of control and a thorough understanding of these methods and their impacts on the environment. Biological, silvicultural, and improved chemical methods alone or in combination must be devised. Research to discover these methods requires basic approaches in physiology, biochemistry, pathology, chemistry, and other disciplines aided by new knowledge and sophisticated instrumentation and techniques. Backstopping this research there must be a strong and sound program of research on the biology, ecology and population dynamics of forest insects.

Substantial progress is being made in this direction. A considerable background of knowledge on the biology of forest insects is being further strengthened. Young, well-trained scientists are working together applying their new skills in the laboratory and the forest to meet today's challenges in forest protection.

USDA and Cooperative Programs

The Department has a continuing long-term program involving forest entomologists, insect ecologists, insect physiologists, insect pathologists, microbiologists, and photo interpreters engaged in both basic and applied studies directed toward the development of safer and more economical and effective methods of direct and preventive control of forest insects. Research is underway at the 10 Regional Forest Experiment Stations, the Forest Products Laboratory, and at the Beltsville, Maryland Forest Insect Laboratory. During the past year a research and development project was established at Berkeley, California to find safe, less persistent insecticides for controlling forest defoliators.

The cooperative aspects of the program have increased considerably this year. Eight basic research grants (PL-934) have been awarded to seven research and educational institutions during this year. Whitten Act Grant (Cooperative-aid) research with universities has increased. Examples of these are: Montana State University--Vegetation classification in spruce budworm outbreaks; Purdue University -- Nutrition of columbian timber beetle related to biological control; University of Massachusetts -- Predators of the red pine scale; and North Carolina State -- Biochemical variations in Dendroctonus frontalis.

Cooperative relations in the form of consultation, services, land use, labor and facilities are engaged in with many universities, State forestry services and experiment stations, lumber and pulp and paper companies, and chemical companies. The cooperation of the Agricultural Research Service has been invaluable in technical consultation on common problems, identification of insects, and in introduction of insect parasites and predators from abroad. The Canadian Department of Forestry has also cooperated in the introduction of parasites and predators as well as participating in technical consultations on common problems.

There are 27 P.L. 480 research grants in 7 countries of the world. Emphasis in research has been changing from identification, collection and shipment of forest insect parasites and predators to studies in biology and ecology of pest insects and their parasites, and biology of certain pathogens. All research is intimately related to the Forest Service program.

The Forest Service scientific effort directed to research on forest insects during the past year totals 95 man-years per year, which includes 8.5 man-years of extramural research.

Progress - USDA and Cooperative Programs

1. Biological Control

Today we are viewing a display of interest and effort in biological control of insects that is unparalleled in the history of entomology. This is not, as it may sometimes seem, an overnight development with scientists "jumping on a bandwagon", though it has been accelerated by recent events. Rather it is largely a result of a series of scientific advances, changes in concepts and a greater recognition of the importance of ecology -- of the forest and its environment and even of man himself.

The limitations of chemical control: its transient effect and cost, the development of insect resistance, and the recognition of its hazards to the environment has encouraged a broader look at insect control. New knowledge, instrumentation and techniques have lead to renewed and intensive investigation of insect diseases, parasites and predators. It has made possible research in depth on genetic resistance of trees. New concepts in insect control involving sterilization of the insect, feeding stimulants and repellents, sex attractants and other approaches involving the insect's biology offer highly promising forms of control.

Our insect ecologists, physiologists, pathologists, and others are making substantial contributions toward biological controls. These will not, however, come rapidly. The research is complex; it requires a thorough understanding of the biology, nutrition, and behavior of the pest insect and its controlling agents and the influence of environmental factors. We can nevertheless be confident that safe, long-lasting methods will be developed which in themselves or in combination with other methods will prevent or suppress damage to forests.

a. Insect parasites and predators. Intensive laboratory studies to determine the effects of various factors on the biology of two ichneumonid parasites, Apechthis ontario and Itoplectia 4-cingulatus are in progress using the greater wax moth, Galleria mellonella as host. It has been demonstrated that photoperiod during development influences diapause (inactivity) in both parasitic species; a high incidence of diapause occurs at day lengths shorter than 16 hours. The incidence of diapause is not influenced by age of the parent female, the photoperiod to which

she is exposed prior to and during oviposition, or the time since her last oviposition. The species I. 4-cingulatus develops eggs faster, lays more per day, lays a greater total number and parasitizes successfully a greater percentage of its hosts than does A. ontario. Finally, while A. ontario parasitizes slightly more hosts at high light intensities than at low light intensities, I. 4-cingulatus parasitizes many more.

In the Northwest, it has been determined that, of seven parasitic species, the two most important parasites (Diptera) of hemlock looper larvae attack them during the fourth and fifth instars. Little parasite flight or predator activity was found to occur during the second and third looper instars, when chemical control is usually applied. Thus we have a compatibility between chemical and natural control.

With the release of the predaceous bug, Tetraphleps sp. (Hemiptera: Anthocoridae), a total of 23 species and 65,554 individual insect predators have been introduced to control the destructive balsam woolly aphid in the Pacific Northwest. Five of the species have become established, but it is not yet apparent that they have been successful in reducing aphid populations sufficiently to prevent tree-killing. Success of the liberation of Tetraphleps will not be known until 1965.

In the Blue Ridge mountains of the Southeast three species of balsam woolly aphid predators imported from Germany have become established. Aphidoletes thompsoni has shown promise, but its effect in the field has not been fully evaluated. Another predator, Laricobius erichsoni has increased considerably in numbers since its release in 1962. The beetle, Aphidecta obliterata, introduced in 1963 has been found to be capable of substantial population increases following release of small numbers of this beetle, particularly where aphid populations are low. North Carolina is the only area in North America where this species has become established. Since insecticidal control is expensive and feasible only near roadsides accessible by heavy equipment necessary for this type of control, increased reliance is being placed on natural predators to control the woolly aphid.

In a study to establish biological control of the larch casebearer in Idaho, success has been achieved in establishing the hymenopterous parasite, Agathis pumila at certain colony sites. Efforts are underway to develop rearing methods to furnish parasites for wider distribution in the casebearer infested area.

The gregarious ectoparasite Bracon politiventris was an important factor in the mortality of large spruce budworm larvae in 1963 outbreaks. Study of its biology was considered essential. The female moth may lay as many as 178 eggs. Development from egg to prepupa required 3 days at 25° C. and 70-percent relative humidity. A cold period of several months is necessary for development of prepupae to adults. Other insect parasites of the budworm are being studied to evaluate their relative effectiveness as control agents.

A key has been prepared which separates the genera of adult hymenopterous parasites of the spruce budworm in northern Minnesota. Included is a list of all species recorded from thousands of rearings from 1956-1961. Seven insect families are represented that include 36 species.

Three species of braconid parasites have been received at the Central States Station from France for study on control of the smaller European elm bark beetle, vector of the Dutch elm disease. One of the parasites, Dendrosoter protubernas, has been reared in the laboratory; research on its biology and ecology are in progress to find means of mass rearing it for release in test plots.

Valuable information has been obtained about a primary predator of the red pine scale, Matsucoccus resinosae, killer of young red pine. The predator is an anthocorid recently identified as Elatophilis (Xenotracheliella) inimica. It has been found in New Jersey, New York, Connecticut and Massachusetts only where the scale is present. Research has provided information on the morphology of the predator, its mating, egg laying and feeding habits. The intermediate legless stage of the scale is particularly susceptible to Elatophilis. Though a 2-year population buildup of scale appears necessary before the predator becomes effective and some tree injury occurs, tree killing may be precluded by action of the predator thereafter.

After 10 years of defoliation damage to Appalachian hardwoods in Georgia, North Carolina, and Tennessee, the elm spanworm epidemic recently declined rather suddenly. The decline was due largely to parasitism of spanworm eggs by Telenomus alsophilae. Recent studies revealed that the adult parasite builds up in fall cankerworms, a less serious hardwood defoliator, emerges from this host about mid-April and attacks elm spanworm eggs at that time. This egg parasitism of elm spanworm accounts for its sudden change in population dynamics. Research indicates egg populations must be sampled after mid-April in order to predict the potential larval population of the spanworm.

The adults of Thanasimus dubius, primary predator of the southern pine beetle, may mate at least 12 times during their lifetime in the laboratory. When ready to lay eggs, the females move about nervously on the bark seeking oviposition sites. The ovipositor is forced into the soft outer bark from the edge of a bark crevice and eggs are deposited singly in bark punctures.

b. Parasitic mites. Exploratory research on the ecology of the Black Hills bark beetle at the Rocky Mountain Station revealed 15 species of mites on the beetles or in beetle galleries. Many of the mites are known to be predaceous, but in no instance could actual mite predation be observed on eggs, larvae, pupae, or adults of the beetle.

Thirty-four species of mites found in association with the southern pine beetle have been identified and their general habits explored. About 23 species are parasitic or predaceous on various life stages of the beetle. It appears quite possible that some of the most promising species may be mass reared in the laboratory and released in efforts to control the bark beetle.

c. Parasitic nematodes. Research has been in progress to discover techniques of rearing nematodes, which are parasitic on bark beetles, as a means of biological control. Six species of external nematodes, parasitic on the roundheaded pine beetle, Dendroctonus adjunctus, and the Engelmann spruce beetle, Dendroctonus obesus, were successfully reared on culture media composed of freeze-dried phloem of ponderosa pine or Engelmann spruce, agar, and distilled water. Internal nematode parasites, which are more effective against bark beetles, could not be reared on artificial culture media.

d. Insect Pathogens. Substantial progress has been made in studies on the biology and mode of action of organisms causing disease among destructive insects, and in developing techniques for studying associated phenomena. In a study of the role of blood cells in insect disease, the hemocyte count after introduction of various kinds of particles into the hemolymph was investigated to determine the pattern of phagocytic response of blood cells. This is the first step in studying the role of blood cells in the movement of viruses from the gut to the site of primary infection

and the process of initiation of viruses in caterpillars. Injected virus capsules did not change the total hemocyte count of armyworms, but the total hemocyte count decreased during the time larvae fed on virus-contaminated foliage. It was shown that the type of rearing method influences variation of blood reaction to foreign particles. Comparisons are being made of groups of caterpillars reared on natural and semi-artificial diets. Specifically, studies have demonstrated that both live and killed Bacillus thuringiensis are phagocytosed by micro- and macroplasmatocytes, but live bacilli cause the phagocytes to break down.

Field testing of Bacillus thuringiensis against the hemlock looper was continued to see if delayed or indirect control benefits, such as an increasingly favorable host-parasite ratio, occurred. Results showed no appreciable reduction in populations until larvae were nearly full grown, when effects of insect parasites and disease become evident. It was concluded that indirect effects of the application of Thuricide 90-T contributed nothing further to the initial direct effects, already determined to be inadequate for economic control. No further field testing of Bacillus thuringiensis will be done until the material is improved, particularly in regard to persistence and viability of the residue on foliage.

A pilot study to control the tent caterpillar, Malacosoma fragile incurva near Tucson, Arizona, has shown promising preliminary results when infested cottonwood and willow were treated by helicopter with a nuclear polyhedrosis virus and Bacillus thuringiensis. Approximately 80 acres were treated with 2 gallons per acre of a 20-percent corn syrup-water formulation containing 50 billion polyhedra and 30 ml of a commercial Bacillus preparation, Thuricide 90 T. After 24 days, 81 percent of the caterpillar colonies on cottonwood and 66 percent on willow contained disease-killed larvae compared to 7 percent in the untreated area.

A number of promising pathogens of the gypsy moth have been discovered in field populations of the insect. Several isolates of a spore-forming, crystal-producing bacilli were found to give a higher kill than available preparations of Bacillus thuringiensis. Also isolated were motile, yellow-pigmented Streptococcus faecalis as well as a new species of Proteus, a bacterium producing a mucoid slime which appears to be a partial cause of a common dessication condition lethal to the gypsy moth. Viable slime-producing cells and dried slime material of Proteus myxofaciens were fed to gypsy moth larvae. The dessication syndrome appeared in untreated as well as treated lots, but was significantly higher in the latter.

Problems with commercial preparations of Bacillus thuringiensis and its effect on the gypsy moth in the laboratory have been under investigation. Results have shown that the improved liquid formulation (Thuricide 90 TS Flowable) fed to gypsy moth larvae was significantly more active than prior preparations. Other tests showed that viable spore count will be reduced with storage time, but the biological activity against second instar gypsy moth larvae is not necessarily reduced. High temperature, however, does reduce biological activity significantly. Biotrol 183, a wettable powder preparation of Bt proved to be as effective as Thuricide 90 TS against gypsy moth larvae.

Thuricide 90 TS Flowable was effective against young fall cankerworm larvae in the laboratory, when applied in dosages of one pint or more in 2 gallons of water. A 100 percent kill occurred in 72 hours when larvae fed on foliage of potted oak seedlings dipped in the B.t. mixture.

Significant results are being obtained on the mode of reproduction and propagation in Bacillus thuringiensis at the Forestry Sciences Laboratory in the Research

Triangle of North Carolina. Studies on sporogenesis are in progress. In view of the proven mutability of B. thuringiensis, new and interesting variants of this organism are being isolated and studied at this time.

The needles of pitch pine, Pinus rigida, have been found to contain antimicrobial substances which are antibiotic to Bacillus thuringiensis. A technique has been developed at Beltsville, Maryland, for purification, separation, and isolation of anti-bacterial substances in the foliage. Extracts of pine foliage were subjected to both strongly acid and strongly basic ion-exchange resins. Thin layer chromatography of an active fraction demonstrated the presence of five antibiotic substances. Substances antibiotic to Bt. were also found in foliage of Pinus sylvestris, Populus sp. and Taxus sp. The feasibility of developing a strain of Bt resistant to anti-bacterial substances found in leaves is now being investigated.

Studies were made in the Northwest to determine if resistance to polyhedrosis virus infection can develop in insect populations subjected to repeated exposure to the virus. Using the armyworm, because it is multivoltine and has a relatively short life cycle, no increase in resistance was noted after treatment of seven generations with an LD_{40} dosage of nuclear polyhedrosis virus. Also, no mortality from polyhedrosis in the untreated progeny of any treated generation has been found, indicating an absence of transovarial transmission of active virus from parents surviving an LD_{40} exposure. Except for a sharp increase in susceptibility to virus infection for a brief period following each molt, the armyworms become more resistant with age.

Research on the nuclear polyhedral virus disease of the Douglas-fir tussock moth, Hemerocampa pseudotsugata, in the Northwest, indicates that the virus disease plays an important role in the termination of outbreaks of this insect. In field populations studied, mortality due to polyhedrosis was common in first and second instar larvae with a second wave of mortality occurring in late third and in fourth instar larvae. This latter mortality was apparently due to contagion from the initially diseased larvae. Few tussock moth larvae survived to pupation in Washington populations. The above described polyhedrosis of early instar larvae appears to be caused by external surface contamination of the eggs. Studies are in progress to determine the approximate virus spray coverage necessary to control tussock moth larvae at any given age.

A study on the role of nuclear polyhedrosis in the population dynamics of the oak looper, Lambdina fiscellaria somniaria indicates that highest populations of the disease organism occur in areas suffering the first year of heavy defoliation. During the last two years, the virus disease has been present to some extent throughout the population including newly infested areas. Thus, it appears that once established, the polyhedrosis moves out with the insect population to new areas of infestation.

e. New Approaches to Insect Control

It has now been positively demonstrated that a powerful sex attractant is present in the adult female of the carpenterworm, a trunk borer that causes serious degrade of valuable southern hardwoods. In forest tests, 5 caged virgin females attracted over 1500 male moths. Of males released 1 mile from the females, 7% were recovered; 1/2 and 3/4 mile releases yielded 20% recovery. Extracts from virgin females attracted males in the laboratory and the forest. The attractant may ultimately be used as a trapping tool to estimate population levels and to control local populations with chemosterilants or insecticides.

Encouraging discoveries are being made in efforts to explain tree resistance to bark beetle attack and to find ways of employing the phenomenon in preventing tree killing by bark beetles. Studies on the terpene composition of oleoresins of ponderosa pine were continued. It has been found that synthesis of monoterpenes is perennially constant, and that there is little or no inter-ring movement of the resin. Inverse relationships were found in the amount of β- pinene and Δ3- carene in 64 ponderosa pines in the central Sierra Nevada. Success has been obtained in attempts to induce western pine beetles to attack pines for determining the resistance of trees to beetle attack. Tree killing was obtained by en masse forced attack on individual trees coupled with the application of either physical or biological stress. Some agreement with laboratory vapor toxicity tests was achieved in that Jeffrey x Coulter hybrid pine was resistant, ponderosa x Washoe hybrid was not resistant, and the Jeffrey x ponderosa and ponderosa x Apache hybrids were intermediate.

A feeding stimulant has been isolated from dry powdered elm bark; it may serve to provide a chemical basis for explaining host selection by the smaller European bark beetle and ultimately contribute toward a control by trapping or other biological means. It was isolated from elm bark by an ethanole extraction technique. Partitioning of this extract between chloroform and water followed by bioassay of the fractions indicates the active material to be chloroform soluble. Further fractionations are in progress. In another related study, paper chromatographic analysis of elm bark has shown the presence of the sugars, glucose, sucrose, fructose, and galactose. All of these sugars have been assayed as feeding stimulants separately, in combination and at various concentrations; no feeding stimulation of elm bark beetles could be achieved when these sugars were incorporated in a feeding substrate composed of agar, cellulose powder, and water.

A feeding stimulant response has also been obtained with the mimosa webworm. Extractions were made from honey locust leaf powder using alcohol; this was followed by partitioning of the extract between chloroform and water. Results showed a water soluble fraction to be active as a feeding stimulant when incorporated into a feeding substrate composed of agar, cellulose powder, and water. Fecal pellet counts served as an index of webworm feeding activity on discs of the agar diet. Attempts to fractionate the active water fraction are now in progress. The information gained from these studies may be useful in future work on host-alteration as a method of controlling these host-specific insects.

A fecal pellet count technique has been developed to investigate feeding stimulation by gypsy moth larvae. Dried leaf powders were made of red oak, poplar and red maple which are highly, moderately and little preferred hosts, respectively, and of ash which is never eaten. These were tested in a neutral agar-cellulose carrier at two concentrations. For comparison, the larvae were also given one-inch leaf squares of the above-named species. Laboratory results were not consistent with feeding behavior of larvae in the field especially in third instar larvae; there was no discrimination in their feeding on the foliage squares or the leaf powders in the laboratory. The fact that ash was readily fed upon in the laboratory indicates that in normal foliage there is a complete lack of a feeding stimulant or a strong repellent or a feeding inhibitor that is altered or nullified when the leaf is removed from the tree.

Composition of oleoresins appears to be of critical importance in the resistance or susceptibility of southern pines to attack by tip moths (Rhyacionia spp.). Chemical and physical characteristics of pine resins are being investigated at the Forestry Sciences Laboratory in Athens, Georgia, to determine the physical or

chemical actions involved. The oleoresin of resistant slash pines loses terpenes rapidly and a hard amorphous cover forms that prevents further loss. The susceptible short-leaf and loblolly pine oleoresins lose terpenes from the inside out and remain gummy on the surface until crystallization is complete. This permits the tip moth larva to remain active and eventually destroy the pine buds. An explanation of these phenomena could lead to production of resistant pines through genetic or environmental manipulation.

A 99 percent reduction in black locust borer reproduction has been achieved with the chemosterilant ENT-50990 in the laboratory at Delaware, Ohio. After previously mated females made tarsal contact with the chemical, all eggs produced were nonviable. Field cage studies in which the chemosterilant was applied to living host trees produced negative results. Methods are now being studied to find ways of successfully sterilizing these insects in the field.

In a study of black locust varietal resistance to attack by the locust borer, evidence suggests that site is more important than tree variety in relating to attack severity. Research is now underway to evaluate the resistance of different strains on a variety of sites.

Tests were conducted in the Northeast to determine the efficiency of the sterile-male release technique in reducing populations of the gypsy moth. Male pupae were irradiated with a Cobalt-60 source. The effect of irradiated males in test plots was measured by hatch of eggs from normal females. Results of the study indicate that the dilutions of irradiated males used were not sufficiently high to produce the high degree of control desired and that the irradiation treatment did not sterilize the males to the level expected and/or the treated males were not fully competitive with normal male moths. Further tests on this method will be conducted to provide more rigorous experimental conditions.

A breakthrough in the field of bark beetle attraction has been made by scientists of the Stanford Research Institute under a recently executed research contract. Two compounds that are the active sex attractant ingredients of the frass of male Ips confusus have been isolated and identified. While the isolation and identification are significant in themselves, the development of the techniques involved is a major contribution. Undoubtedly, the methodology will enable recovery of attractant compounds from other insects.

f. P. L. 480 Projects.

(1)-INDIA

a. Survey for natural enemies of Adelges spp. on silver fir in the Himalayas. Studies on the biology and life history of Adelges spp. and life history studies of its primary predators continued. Populations of the predators, Anystis sp. and Tetraphleps sp. reached a peak level in April and May, respectively. Leucopis spp. were the dominant predators of Pineus sp. from January to May. Forty-three shipments of Leucopis pupae and 10 shipments of Tetraphleps adults were dispatched to Moorestown, New Jersey, during the past year.

b. Biological Control - Survey for natural enemies of the gypsy moth. Studies on the natural enemies of Porthetria spp. in India have revealed heavy parasitism of caterpillars by unidentified nematodes. Two new Eulophids, pupal parasites, and an Encyrtid egg parasite have been found. In addition several new caterpillar parasites, and a carabid, predaceous on eggs and caterpillars, have been reported. Studies on

the biological significance of these parasites and predators are in progress. It has also been determined that a species of Porthetria being studied in Kashmir, Kulu, and Kotgarh is not dispar.

c. Survey for natural enemies of Hypsipyla robusta (shoot borers) in India. Tetrastichus spirabilis, a pupal parasite, was found to be the most important natural enemy of Hypsipyla in certain areas of India. Ephialtes sp. has been bred from caterpillars. Laboratory rearings and studies on the biology of these parasites are in progress.

(2)-PAKISTAN

a. Investigations on the predators of Adelges (the balsam woolly aphid) on fir. Some 39 insects and 2 mites have been observed in association with Adelges-infested firs. Of these, 24 species of insects and both species of mites played a significant role in the destruction of Adelges. Emphasis has been placed on the study of certain predators, especially Chrysopa spp. and Leucopis spp. Studies on Chrysopa murreensis and C. albolineata have yielded descriptions of immature stages, biology, and feeding habits of these species. Similar studies have been conducted on Leucopis spp., Syrphus sp. and Tetraphleps sp. Some of these predators have been shipped for trials in the U. S., but there has been no evidence of establishment to date. Studies are in progress on synchronization of predator activity with that of the host in the release areas in the U. S. Consideration is also being given to the climatic regimes occupied by the aphid and its predators in Pakistan and North America.

b. Studies on the natural enemies of insect pests of West Pakistan forests. An intensive study of insect and mite pests of West Pakistan high altitude forests and their natural enemies was continued. Large numbers of pests and their parasites have been collected and reared. Various aspects of the biology and life history of these insects are now being investigated in the field and the laboratory. About two dozen species have been observed feeding on seeds and cones; some of these insect species are under detailed investigation.

(3)-FINLAND

a. Orienting stimuli guiding insect pests of forests to suitable trees. Studies have resulted in the isolation of a chemical component from Pinus silvestris phloem that exerts a definitive attractive effect on the beetle Blastophagus piniperda in choice chamber tests. This same component, or one very similar, has been isolated from synthetic terpineol; this component has been shown to be α-terpineol. It has been determined that the terpineol has an attractive power almost equal to that of the active fraction from the host phloem. Studies to confirm laboratory results under field conditions will be carried out during the coming season.

(4)-POLAND

a. Investigations into the activity of the parasite, Trichogramma embryophagum introduced into the forest environment, with special attention toward its capacity for spreading. Using sticky, yellow balls to capture Trichogramma adults, it has been possible to elaborate a seasonal pattern of fluctuation in population density, with populations being highest in May and June, and at low levels in the winter and spring. In pine forests attacked by Acantholyda nemoralis, populations of Trichogramma were at maximum density in May. The main established causes of

Trichogramma mortality are the activity of parasites and predators and "natural" mortality of larval populations inside the host egg. Investigations were also carried out on a method of marking Trichogramma with radioactive P^{32} Satisfactory results were obtained.

b. Studies on the development of improved strains of parasites of forest insects. Various geographical strains of the hymenopterous parasites, Dahlbominus fuscipennis and Dirhicnus alboannulatus have been studied. It has been shown that pure strains may be developed in the laboratory which have greater possibilities as biological control agents, i.e., greater longevity of females and increased fecundity, than certain wild strains. Cross-mating of some of these strains has further increased the biotic potential of these parasites. Strains inbred for 4-6 generations did not show any decrease of biotic activity.

(5)-SPAIN

a. The study of parasites, predators, and diseases of the gypsy moth and the possibility of their application in biological control. The gypsy moth parasites, Apanteles vitripennis, Brachymeria intermadia, and Tricholyga segregata have received considerable study in Spain. Although it has been possible to rear these insects in the laboratory, rearing from field collections is still the best source. Several thousand individuals of each of these species have been shipped to the United States for release in gypsy moth-infested areas. Comparative studies on the climate in collecting and in release areas are in progress. Dust and spray treatments with Bacillus thuringiensis var. Anduze have been conducted against gypsy moth larvae. Evaluation of these treatments to determine the success of this method is in progress. A study on B. thuringiensis toxins has also been started.

(6)-YUGOSLAVIA

a. Study of the polyhedral virus disease of the gypsy moth. During 1964, Yugoslavian scientists were engaged in a program of breeding gypsy moths in four geographically and climatically different regions. Viruses were isolated from caterpillars in all regions and afterwards purified. The first experiments on serological investigation of these four virus groups are now in progress. In another phase of the study, gypsy moth eggs were irradiated with radioactive Cobalt-60. Radiation effected egg hatch, in that treated eggs hatched late; high radiation doses killed the eggs. Lower doses of irradiation appear to stimulate caterpillar growth; on the contrary, higher doses depress caterpillar development. Irradiation of eggs also increases caterpillar mortality from polyhedral disease. In addition, radiation shortens the time required for the virus to kill the host.

2. Chemical Control

At the present time chemical control is the primary tool employed for controlling destructive forest insects. Though biological, cultural and integrated controls will ultimately be developed, chemical methods will continue to play an important part in forest protection. They will be needed to deal with sudden unforeseen destructive outbreaks or those that for some reason defy control by other means. In the search for safe pesticides, basic study on the chemicals, their behavior in the environment and their mode of action on the target insect and its associates is required. Noteworthy progress is being made in this direction, particularly at Berkeley, California where a project was recently established to conduct intensive research in this field.

a. Systemics. Nursery and individual tree treatments have been developed for the control of the mimosa webworm on ornamental honeylocust. The systemics Di-Syston and phorate were applied in granular form in the nursery; root implants of Bidrin were used on individual trees. Season-long protection was achieved with little or no hazard to man or other animals.

Improvements in the performance of Bidrin for the control of white pine cone beetle has been achieved largely by the use of correct methodology. Studies were made of different formulations, concentrations, dosages and schedules. The material was injected into the tree through 1/4-inch holes drilled one inch deep at specified intervals around the hole 3 feet above the ground. Treatments several weeks before cone beetle emergence did not provide protection to maturing cones.

Technical Bidrin applied at a later date gave the best protection (21.1 percent cone survival). In all treatments, there was considerable variation in the rate and amount of uptake; some phototoxic effects were also noted.

It has been demonstrated in the Southeast that Thimet granules, properly handled and applied to the soil at the base of potted grafting stock and outplanted loblolly pine seedlings, has successfully prevented tip moth infestations. Untreated controls repeatedly suffered terminal tip moth injury. No phytotoxicity was observed with the concentrations and methods used.

b. Conventional Methods. At the Berkeley insecticide evaluation and development laboratory preliminary evaluation of 24 different materials for defoliator control has been completed. Several of these materials gave higher contact toxicity than any materials used or tested against these insects in the past. These chemicals are non-persistent materials with characteristics which should allow their use with little or no effect on other organisms. A stabilized pyrethrin formulation has been tested with success in the laboratory; field studies on this compound will follow. Neopynamin and dimethrin, pyrethroid-type materials were tested against the pandora moth with relatively poor results. These compounds will be tested against the spruce budworm. Toxicity tests on the pandora moth and Douglas-fir tussock moth are continuing.

Studies on DDT and its biological breakdown product DDD have shown that C^{14}-DDT incubated with bovine rumen fluid, lake water, and aqueous solutions of reduced porphyrins indicates a possible mechanism for this conversion in biological systems. In certain situations, DDT residues could thus serve as a continuous supply or precursor for the formation of DDD.

In California, studies on the effect of aerial sprays of malathion on the parasites of the lodgepole needleminer indicate that these sprays, applied by helicopter, have little effect on the parasite while giving 90 percent control of the host insect. Host-parasite associations, before and 2 to 4 years after malathion spraying, remained unchanged even after low host population levels were achieved through spraying.

A study of the ponderosa pine tip moth has shown that, where necessary, forest seed orchards and other high value plantings of ponderosa and other western pines can be satisfactorily protected from damage by this insect with a simple spray application of DDT.

In Idaho, as little as 8 fluid ounces of technical grade malathion per acre, applied by helicopter, gave 92.4 to 99.6 percent mortality of fourth instar larch casebearer larvae.

A portable mistblower test to compare malathion and DDT for contol of the Saratoga spittlebug was conducted in Michigan red pine plantations. The results of these tests indicate that malathion, at 1/2 lb. per gallon per acre, was as effective as DDT at 1 lb. per gallon per acre. Large acreage treatments by helicopter are planned for 1965.

Studies in the Central States indicate black locust damage may be reduced by applying insecticide to only a part of the stand since each beetle crawls over the trunks of many trees. An uncompleted study has shown that when 60 percent of a 500-tree plot was sprayed with a 1 percent DDT emulsion, the borer attack was only 0.2 percent as opposed to 7 percent attack in an untreated control plot.

A comparison of two methods for the control of southern pine beetle--spraying standing trees and the present felled-tree spray treatment--indicates that either method is equally effective. The standing-tree spray method requires twice as much chemical and may be used only on trees accessible by jeep and less than 40 feet tall. However, it is 12 times faster since felling and trimming of trees is unnecessary. Therefore, it has definite advantages in economy of time and labor if the nature of the stand permits its use. It is of particular value when speed is essential in controlling rapidly spreading infestations.

Sprays of a 1.0 percent gamma BHC emulsion plus a wetting agent protected pine stumps and live trees for 6 months against the black turpentine beetle. Control success was equal to a commonly used 0.5 percent BHC in oil solution; the latter mixture is more costly and inconvenient to use.

The insecticide Sevin is highly promising for control of the slash pine seedworm, Laspeyresia anaranjada, in the Southeast. Trees sprayed with a concentration of 0.5 percent Sevin and 4 ounces of Plyac spreader-sticker per 100 gallons of water had 2.0 percent of their second year cones infested, while 13.0 percent of those on untreated trees were infested.

Laboratory and field tests on surface application, in pellet form, of Mirex has shown this chemical to be a promising substitute for fumigants in the control of the Texas leaf-cutting ant. As compared to fumigants, Mirex is cheaper, gives more consistent control, and extends the time when colonies can be treated effectively.

Studies at Beltsville to evaluate mechanical factors affecting the atomization of oil-base insecticides in forest spraying have yielded new knowledge on behavior of aerial sprays. These factors were given particular attention: airspeed of the plane; direction, size and type of orifice; and spray pressure. Airspeed and direction of orifice in relation to thrust line of the plane were the most important factors affecting atomization. Large nozzles and increased airspeed decreased the mmd (mass median diameter) of the spray by 60 percent. There was no practical difference in mmd of the spray when flat spray nozzles were directed forward and down at 20° or 45°. When hollow cone spray nozzles were used, there was an increase in mmd when they were turned from a forward to a rearward direction. Spray pressure was not found to be an important factor in atomization of aerial sprays.

Preliminary studies of the aerial application of water sprays indicates that atomization is much coarser (about twice the mmd) than the atomization of oil sprays from identical spray nozzles. This may pose serious problems in obtaining uniform coverage of water sprays applied from the air.

Electrostatic charging of sprays appears to improve aerial spray behavior. Initial basic laboratory studies at Beltsville indicated that charging of water sprays produces a more uniform spray drop size and could result in more uniform dispersion of the drops and a greater deposit on foliage. A spray charging device designed for use on an airplane may be a means of increasing efficiency and effectiveness of aerial sprays.

Studies on spray distribution patterns of a TBM spray plane have shown that a short trailing edge nozzle boom was as satisfactory as a full span underwing boom. In addition, the short boom creates less aerodynamic draft on the plane.

c. Fumigants. Recent evidence has shown that epichlorohydrin and Glycidyl phenyl either prevents corrosion of tin-plated containers for seven years, when used at rates of 0.05 pounds per gallon of ethylene dibromide. This type of container will corrode in 6 months without the inhibitor when used for storing emulsifiable dibromide packaged for bark beetle control.

3. Silvicultural Control

The scientific culture and management of forests is one of the most promising means of preventing forest insect outbreaks. Though examples of such control of our most serious pests are relatively few, they demonstrate the value of the methods under certain circumstances. Development of the method is time consuming and costly for it requires thorough knowledge of the insect and the host and the multitude of environmental factors influencing them. However, as entomologists delve more deeply into the biology and ecology of insects and forest scientists learn more about forest ecology, silvicultural controls will be more easily attained.

a. Bark Beetles. In California, 25 years of data has shown the mountain pine beetles exhibits an attack preference for mature and overmature sugar pines with decadent crowns. In second-growth trees, beetle outbreaks were characterized by indiscriminate tree killing, with drought and heavy snow breakage contributing toward attack susceptibility.

b. Defoliators. Different forms of cutting --- partial-cutting, clear-cutting and no-cut --- do not result in significant differences in damage from spruce budworm defoliation. However, cull or seed trees left in the overstory from previous harvesting operations contributed to occurrence of infestations that later damaged advanced balsam fir regeneration. Older trees harbor larvae which disperse into the area from surrounding infestations.

c. Plantation Insects. Silvicultural practices may be an effective substitute for the present method of suppressing the pine root collar weevil Hylobius radicus in the Lake States by insecticidal application. Recent study indicates that, since sunlight appears to repel adults, pruning to permit sunlight to reach the base of trees provides silvicultural control of the pest. Larval population levels on pruned trees dropped to one-third the level of non-pruned check trees in a preliminary test. Since pruning is now recommended for controlling the European pine shoot moth, this practice may serve to control the two insects simultaneously.

d. Miscellaneous Insects. It has been established that the 2-yr. life cycle of the red oak borer is synchronous throughout the entire Central States area from eastern Kentucky and Ohio to Missouri. This fact enables control of the insect by proper timing of timber stand improvement: killing of low quality trees by poisoning (such trees are usually heavily infested with borers). Trees poisoned in mid-June resulted in almost complete control of borers. The practice can reduce borer populations in the forest and the damage to residual stands of upland oak.

Cultural control measures may be used to control insects attacking red pine and white spruce cones in the Lake States based on the fact that most species hibernate in the litter or in the cones on the ground. Thus, fall-burning of the duff or mechanical measures will effectively destroy hibernating adults of the red pine cone beetle. Also, complete removal every year of cones and infesting larvae of the spruce seedworm, Laspeyresia youngava, from white spruce seed-production areas should reduce subsequent infestations.

4. Biology and Ecology

a. Barkbeetles. Substantial progress is being made in research to determine the nutritional requirements for growth and development of the Douglas-fir beetle and to learn whether host selection by this beetle has a nutritional basis. Attempts to develop an optimal artificial medium for larval growth and development has been successful using two different diets, one with and one without the water-binding agent agar. With the latter, 75 percent development from newly hatched larvae to the pupal stage was achieved, while the former (agar diet) allowed only 50 percent development. Both diets contain macerated inner-bark of Douglas-fir, brewer's yeast, the antimicrobial agents sodium benzoate and sorbic acid, and water, adjusted to pH of 4.5 with 2 N HCl. In the field, considerable variation in beetle fecundity and gallery formation was noted from tree to tree indicating possible nutritional differences between standing Douglas-fir trees.

In the Pacific Northwest, results of the first year's study showed that the largest brood of the Oregon pine Ips developed in slash in areas where thinning had been continuous for more than a year, and in shaded rather than exposed slash. Slash 3 to 4 inches in diameter proved optimum, broods were smaller in larger and smaller slash. Brood production was lighter and much retarded in development at higher, colder elevations.

Life tables have been accumulated to develop a preliminary mathematical model for population studies of the mountain pine beetle in lodgepole pine. Data were taken during the egg stage, five periods during larval development, new adult, and parent adult stages. Analysis of data from a plot in the Teton National Forest in Wyoming revealed certain features of brood development that had a strong effect on generation survival measured by production of new adults. Larvae developing in the fall were subjected to mortality factors during the winter, while larvae developing from eggs in the spring escaped these particular factors. The result expressed in life tables showed a much higher generation survival from eggs deposited in the spring.

In western Montana, considerable differences were found in ponderosa pine growing in two ecosystems in 35 plots (totaling 553 acres). Tree species composition, density, tree age classes, and pine tree risk ratings of susceptibility to bark beetle attack were significantly different as were the patterns of tree mortality between stands representing the two ecosystems.

A study on the relationship between fire and beetle attack on burned Douglas-fir trees in Idaho showed that incidence of attack increased with the size of the tree and severity of fire injury to crown and cambium up to the point of death, but decreased sharply with outright fire kill. As a result, salvage cutting should include all large trees, fire-killed trees, and severely defoliated trees.

Exposure of the Black Hills beetle to constant temperature (70° F.) and varying relative humidities revealed that relative humidity has no apparent influence on brood size or rate of its development; nor did humidity affect size of female progeny. Alternating periods of cold temperature and atmospheric pressure had no effect on total beetle emergence.

The emergence patterns of the Black Hills beetle, from ponderosa pine in the central Rocky Mountains, were found similar in rate and time over a five-year period. Emergence begins about July 15 and reaches a peak about August 20. This indicates that control projects should always be planned for completion by July 15.

The overwintering habits of two morphologically closely related species, Ips lecontei and I. confusus were studied in Arizona and New Mexico. Hibernating adults of I. lecontei are found more frequently in ponderosa pine stems of less than 9 inches in diameter. Hibernating adults of I. confusus are located in the largest portion of pinon pine, being most numerous at or near ground level.

Development of rearing facilities for producing the small oak bark beetle and of a culture technique for the individual screening of suspected oak wilt vectors are the major contribution to a study to determine possible insect vectors of oak wilt fungus in the Central States. Studies are now in progress to compare the potentials of various species of oak-inhabiting insects as vectors of the fungus. Some data have been gathered on the life history of the small oak bark beetle in the laboratory, but field data are still limited.

A method has been developed to mass rear and recover the adults of the southern pine beetle, Dendroctonus frontalis, in the laboratory. This now permits year around study of the beetle; it provides specimens for study of diseases, attraction, genetics and other biological phenomena. Adult beetles are released into a 20-gallon metal can containing fresh pine bolts in which air, moisture and light are regulated. New brood adults emerge into collecting jars about 30 days later. Yields vary but average between 7:1 to 10:1 (brood adults = parent adult): a 20:1 yield has been obtained. Rearing techniques have also been developed for Ips calligraphus using approaches similar to the above.

Several artificial diets for the southern pine beetle have been studied including one of a casein-type, and two containing a series of amino acids instead of a protein. The beetle has now been successfully reared from first instar larva to adult on a chemically defined diet containing no liquid or protein sources. The adults are very small and pale, but otherwise normal.

Research on the nutritional requirement of the southern pine beetle is yielding significant findings. Chemical analysis of loblolly pine shows the presence of 8 carbohydrates and 13 amino acids. The same constituents were recorded from bark-infested in the laboratory as from fresh, uninfested material. Qualitatively there is no apparent seasonal change in the concentrations of the free soluble sugars. However, fluctuations in total amino acid content occur during the growing season, being lowest in September; moisture content of the inner bark is also at its lowest level in September.

Study of seasonal variation in activity of the southern pine beetle in east Texas and central Louisiana indicates that numbers and sizes of infestations increased most rapidly during April, May, and June. Beetles attacked upper stems during the cooler months; the lower third of the stems in mid-summer. Changes in attack densities, host conditions, and abundance of natural enemies seemed to account for much of the seasonal variation in brood establishment and development. Prolonged high temperatures apparently limited dispersal and survival in mid-summer. Artificial control measures should, therefore, be intensified in fall, winter, and early spring.

b. Defoliators. Studies on oviposition and fecundity of the black-headed budworm, Acleris variana, were continued in Alaska using field and laboratory reared insects. The number of eggs per female varied from 13 to 179 with the average for moths emerging from field collected pupae being 87 in 1964; laboratory-reared individuals produced significantly fewer eggs. Insects with early seasonal development produced more eggs than those having late seasonal development. Studies to correlate pupal size with adult fecundity indicate that pupal size is only a rough estimate of expected fecundity.

The black-headed budworm in Alaska was found to defoliate western hemlock more seriously than Sitka spruce because the phenology of Sitka spruce is not well synchronized with budworm development. In western hemlock, young budworm larvae bore into buds and remain feeding within the closed bud until the third instar is reached. Sitka spruce buds break before the budworm eggs hatch and the elongating shoot does not provide the needed shelter for survival.

Artificial media have been developed for the year-around rearing of the following defoliators: Douglas-fir tussock moth, oak looper, silver spotted halisidota, armyworm, variegated cutworm, western tent caterpillar, and great basin tent caterpillar. The diet consists in each case of host tree foliage, pablum, and microbial inhibitors, blended and made into a paste. Additional species, including the hemlock looper and the pandora moth, are currently being test-reared on the medium.

Biochemical studies in the Northwest are yielding valuable information regarding the factors responsible for the presence of two color forms of the spruce budworm. A "green" form is found in an extensive area of southern Oregon and northern California, while individuals of a "normal" population of the same species may be found throughout northern North America. Fundamental differences exist between the two forms in regard to absorption spectra of their hemolymph, an absorption maxima of 650-660μ being present in the hemolymph of the green form and lacking at that wave length in the hemolymph of the normal form. Satisfactory methods of preserving the hemolymph have been developed and partial purification of the hemolymph preparation was achieved through solvent extraction with chloroform. Results of preliminary tests suggest that the chloroform-soluble material may be chromo-protein.

Studies of spruce budworm egg mass densities reveal that a 24-inch branch sample can be used instead of the conventional half-branch sample, thus reducing collection time by two-thirds and examination time by one-half.

In the Lake States, a study to determine the effect of light on oviposition by the spruce budworm has shown that illuminated ends of balsam fir and white spruce branches always had four times more egg masses than those in the dark. This occurred regardless of whether the apical or basal end of a branch was illuminated. It appears that oviposition pressure forced normally light-sluggish females to oviposit.

In a study comparing methods of predicting development of the spruce budworm, the degree-hour method was most accurate, but the day-degree method was easiest to calculate and more practical.

Valuable knowledge is being gained from population studies on the gypsy moth in the Northeast relative to evaluation of infestations and proper selection and timing of control techniques, both biological and chemical. Analysis of a 21-year record of gypsy moth abundance in Massachusetts, Maine, and New Hampshire, and a 6-year record for eastern New York, gave the following information: Variation in adult sex ratio appeared to be an important determinant of population trend from year to year; the sex ratio was determined largely by mortality-causing agents operating on the large larvae and pupae; the primary agent affecting male and female larvae differentially was disease, though disease and ichneumonid parasites determined the survival of the pupae; the incidence of disease and ichneumonids in turn were directly correlated with population density of the host insects in that disease and parasite effects were negligible at sparse host levels. It thus appears that the most efficient means of controlling dense populations of the gypsy moth may be through a manipulation of the environment that will increase the incidence of natural disease, or by the introduction of a supplementary disease organism into the population. Maintaining conditions favoring parasitism predation (including birds and small mammals) or the use of sterilized or otherwise genetically altered gypsy moth males would prevent build-up of gypsy moth from endemic to epidemic populations.

Research in the Southeast has shown that the elm spanworm and fall cankerworm exhibit similar characteristics in their responses to population densities and resulting body color. At low population densities, larval color is light, while at high densities the larvae are dark. Crowding yielded darker female spanworm pupae with fewer eggs. Evidence suggests that the color variation in the two looper species is regulated by neurosecretory activity, and this likely affects egg production and duration of life stages.

In another elm spanworm study, it was found that female pupae are significantly heavier than males; pupae of spanworms reared on pignut hickory are significantly heavier than those reared on red or white oak. Spanworms reared on pignut hickory produced an average of 109 percent more eggs than those reared on oaks; pupal weight and egg potential are found to be closely correlated. The eggs are deposited almost exclusively on the underside of branches; generally, eggs deposited on the upper surface of branches do not hatch. Eggs exposed to sunlight in August and September, and in April and May were severely affected, while exposures during November - February did not affect normal hatch.

The pine sawfly Neodiprion excitans which is active during the winter in Florida has been found capable of surviving subfreezing temperatures. Larvae, frozen solid in the laboratory for approximately 24 hours, revived and resumed feeding when air temperatures exceeded 40°F.

c. Seed and cone insects. In the Southwest the seedworm Laspeyresia miscatata which attack ponderosa pine cones, has been found overwintering in old pine cones and pupating before the end of March. Adult emergence and oviposition started about April 7 and continued until May 15. One to five reddish-brown, scale-like eggs were deposited on peduncle scales. It was also learned that a coreid bug, Leptoglossus occidentalis, damaged cones by feeding on the internal structures of the seed. If this feeding occurs before the seed coat hardens, the shell collapses.

In the Lake States the red-pine cone beetle, Conophthorus resinosae was revealed as the most destructive species of red pine cones. However, five other species cause primary damage to cones and seeds of red pine. A key has been developed based on cone damage and larval characteristics which will enable the forester, nurseryman, or entomologist to distinguish between these pests.

The biologies of the acorn-inhabiting curculionid weevils Conotrachelus naso, C. posticatus, and C. carinifer have been studied and new information gathered on rearing methods, oviposition, morphology and behavior. Keys for identification of the mature larvae, pupae, and adults have been prepared. With this infomation, studies can now proceed to evaluate the effects of individual species on oak seeding production and survival.

A compilation of the insects affecting seed production of slash and long-leaf pines has been completed which lists the primary and secondary insects by types of host-tree materials. A key is given for common insect damage to flowers and cones.

The artificial diet for rearing the coneworm, Dioryctria abietella, has been improved by the addition of vitamins C, B_1, and B_6 which increase larval survival by 20 percent. Addition of a cone scale to the medium has reduced larval mortality between hatch and second instar. It has also been found that survival increased and span of life decreased when D. abietella was reared in total darkness.

d. Plantation insects. Results of studies on the Sitka spruce weevil in the Northwest indicate that a hybrid (Picea x lutzii), naturally occurring in Alaska, appears to have a high degree of weevil resistance. The hybrid, which is a cross between Sitka spruce and white spruce, also has excellent growth characteristics. About 50 percent grafting success was obtained when grafting scions from suspected weevil resistant Sika spruce to ordinary Sitka rootstalks. Propagating weevil-resistant material seems possible provided operationally practicable techniques can be perfected.

It has been found that the biology and behavioral characteristics of the European pine shoot moth in western Washington, conform in general to that described for southern Ontario. Peak emergence of the adult insect occurs around June 30 in western Washington.

In the Southwest, studies were conducted to obtain basic knowledge of the life cycles and ecological relationships of three important insect pests of ponderosa pine regeneration plantings. These studies on Cylindrocopturus eatoni, Pissodes yosemite, and Rhyacionia zonzana should enable better evaluations of their importance in the field.

The effects of defoliation of pine in the Lake States by European pine sawfly larvae have been established. Larvae injure their hosts by consuming old-growth needles, debarking, and girdling current-year shoots. Defoliation is responsible for height and radial growth loss, with over one-half of the total defoliation occurring after the peak of the fifth instar. Growth loss appears to be a function of the number of defoliations and the quantity and rate of foliage removed during each defoliation period. Two successive years of defoliations by 25 or more larval colonies caused considerable loss. Since new growth develops while old growth is being consumed by larvae, trees are seldom completely without foliage, which may explain why host mortality seldom occurs.

The sawfly pest of white pine in the Central States has been identified as Acantholyda luteomaculata, an apparent new record for Ohio. The biology of this insect has been studied and a satisfactory sampling method for stages that inhabit the soil developed. Distribution of the larvae in the soil and their relation to defoliation and damage is now being investigated. A paper chromatographic technique for the separation of pigments responsible for red and green larvae of the sawfly has been developed preliminary to investigation of the mechanisms responsible for the color variation. A constant ratio of red to green larvae, and the nature of pigment extractions from these larvae, suggests this mechanism is genetic.

e. Miscellaneous insects. It appears that subalpine firs in the Northwest which are suppressed or growing on poor sites are generally more resistant to balsam woolly aphid than dominants and codominants, and those growing on good sites. Over a 6-year period, 60 percent of the trees have been killed by aphids on a high-site stand as compared to only 25 percent mortality on the low-site stands.

Grand fir continues to show relative tolerance to the balsam woolly aphid. For several years, some 40 percent of the plot trees have been infested, but only 2 percent have been killed. However, many of the trees are becoming deformed, and wood quality and height growth are considerably reduced.

The time of frost occurrence has been found to have a strong effect on the survival and dispersal of the tuliptree scale, injurious pest of poplar regeneration. Young crawlers, following their birth from August into October, normally spread over the foliage and twigs of entire trees. After the young scales are attached to the foliage and twigs they are unable to move. If the frost comes late, as much as 85% of the crawlers drop with normal leaf-fall and perish. If it comes early, before crawlers disperse throughout the tree, leaf area is reduced and crawlers are concentrated on twigs to subsequently attack them.

The ant, Dolichoderus taschenbergi, tends the tuliptree scale for honeydew collection and correspondingly lessens the effect of scale parasites and predators. For example, 73 percent of female scales survive on ant tended trees while only 35 percent survive on trees not tended by ants.

Techniques for rearing the black locust borer to provide a continuous supply of adults for chemosterilant and laboratory studies have been improved. Two methods are presently being utilized. One consists of harvesting field-infested black locust wood, cutting the wood into bolts, and then rearing-out the adults in the laboratory. The other utilizes a semi-artificial diet similar to one used to rear the cotton boll weevil. The main difference is found in the addition of black locust powder and certain fungus inhibitors and an anti-bacterial agent to the food medium. Using this artificial diet, it has been possible to rear a complete first generation and partial second generation. Present data indicate it may be possible to rear 3 to 4 generations per year on the artificial diet as compared to a single generation in the field.

Pine leaf aphid infestation has been found to produce a general reduction in radial increment of white pine and also a modification of the normal pattern of annual increment along the length of the main stem. Greatest growth reduction occurs in the lower stem; branch mortality is greatest in the mid- and lower-crown.

The pine leaf aphid has two true hosts, spruce and eastern white pine, each providing food and shelter for specific stages. A study is in progress in the Northeast to investigate the dispersal of the aphid from spruce to pine, since

injury to the latter host is more serious generally and since it is the more valuable tree species. It appears now that upon leaving its gall on spruce, the aphid is attracted by light, flies upward, is caught by the wind, and finally is attracted visually to white pine (it rarely alights on other tree species). These various behavioral aspects are now being studied.

f. P. L. 480 Projects

(1)-TAIWAN

a. Biological study of the more important pests attacking the genus Pinus introduced from the U.S.A. A study of the more important insect pests attacking American pine trees in Taiwan has been conducted since July 1963. Of the 205 species of insects found in stands of American Pinus, only 5 were regarded as major pests. Life history and population density studies on three of these pests, Dendrolimus punctatus, Dioryctria pryeri, and Neodiprion japonica were conducted in the laboratory. In addition, rearing studies were begun on the jewel wasp, Pteromalus sp., a parasite of D. punctatus. This parasite is one of four found to have a high parasitic ratio on American pine insects in Taiwan. Studies on Apanteles sp., a parasite of D. punctatus eggs, and Monodontomerus sp., a parasite on the pupa of N. japonica are also in progress.

(2)-POLAND

a. Insects noxious to young stands of pine. Studies primarily concerned with Rhyacionia buoliana biology, ecology, and population dynamics have continued. Larval mortality in two consecutive seasons has been found to be relatively high in winter, even during rather mild winters. It has been shown that parasites, e.g. Orgilus obscurator, are considerably more active in forest or old plantation situations than young plantations or singly-planted trees. Another interesting finding is the relatively higher percentage of R. buoliana females in a population from open areas as compared to forested areas. These two factors, higher breeding potential and lower parasite infestation, seem to account for R. buoliana "selection" of sparsely planted pines. Studies on other parasites associated with R. buoliana are in progress.

b. Research on the growth and development and disease susceptibility of some species of trees from the United States of America to be planted in certain climatic regions of Poland. Studies have been conducted in the nursery and in the field to determine what injurious insects, if any, attack seedlings and transplants of pines received from the U. S. Studies were primarily conducted on Douglas-fir, eastern white pine, lodgepole pine, western red cedar, western hemlock, Sitka spruce, and eastern hemlock. In the nursery, no insect damage was noted, except sporadic damage by cockchaffer grubs. However, in plantations, the pine weevil, Hylobius abietis was observed damaging western red cedar, eastern hemlock, and Douglas-fir. It was confirmed that the pine weevil was more likely to attack the seedlings of eastern hemlock and Douglas-fir than those of Pinus silvestris. Seedlings of western red cedar were more rarely injured by insects than were eastern hemlock. Some weevil damage was noted on lodgepole pine and eastern white pine. In some localities, damage by the sawfly, Acantholyda hieroglyphica Christ. was found.

(3)-SPAIN

a. Pests of poplars and preventive and curative methods of control. Research concerns the biology of certain poplar insects, especially emergence dates and

oviposition habits. Insects receiving considerable study were Paranthrene tabaniformis, Crytorhyncus lapathi, Saperda carcharias, and S. populnea; there are no significant differences among attacks on different clones. Laboratory studies are in progress to determine factors involved in clone selection by C. lapathi. Thin layer chromatography of poplar bark samples to detect sugars, glucosides, and amino acids are in progress in attempts to relate the presence and concentrations of these bark constituents to insect host selectivity. A water extract of bark has stimulated C. lapathi feeding in a laboratory multiple choice test. In studies on chemical control of poplar insects, trunk spraying to control P. tabaniformis reduced larval destruction by 50%, but was not considered efficient. Spraying of poplar trunks with 0.5% dieldrin to control C. lapathi was considered more successful. Results of spray treatments indicate that S. carcharias may be controlled very efficiently by spraying the lower part of poplar trunks with Guthion.

(4)-BRAZIL

a. Disease and insect susceptibility and species adaptability of some North American pine species planted in Sao Paulo. Outplantings of pine have been made at 4 different locations in random blocks (12 x 4), comprising twelve treatments and four replications, and in Latin squares (5 x 5) including five treatments and 5 replications. The injurious species of insects found thus far are being studied.

(5)-COLOMBIA

a. Diseases and insect susceptibility and species adaptability of North American forest trees planted in Colombia. Various pine species have been planted in several plots in Colombia. No significant findings on insect susceptibility have yet been reported.

(6)-URUGUAY

a. Disease and insect susceptibility and species adaptibility of North American conifers planted in Uruguay. Mild attacks by insects were reported in certain areas planted to pines, but insect losses were controlled with Endrin. Certain areas were heavily attacked by Evetria buoliana; larvae and pupae of this insect, some attacked by parasites, were collected for further study. Satisfactory control of this insect was attained by aerial application of parathion.

5. Wood Products Insects

The tremendous expansion of housing construction associated with increased population and urbanization and the increased emphasis on quality products continues to magnify the importance of protection of wood and wood products. While effective methods have been developed for preventing and controlling some of the primary insects, improvements are needed. For example, in termite control more needs to be known about the behavior of chemicals in different soils; and biological and structural control methods need study. Also, methods are needed to deal with the innumerable species such as powder-post beetles, ants and borers which, though moderately severe individually, in aggregate they pose a serious problem. Much needs to be learned about the biology and environmental requirements of these insects before satisfactory controls can be developed. It is in this direction that current research is moving.

a. Termites. Granular formulations of five insecticides (containing 10 percent active ingredient) continue to give 100 percent control of termites after 6 years.

They were applied at the following rates per 10 square feet of soil surface: aldrin, 0.5 pound; gamma BHC, 0.9 pound; chlordane, 1.0 pound; dieldrin, 0.5 pound; and heptachlor, 0.5 pound. (These are comparable to dosages of water emulsions applied for termite control). Studies indicate that there is negligible movement in soils of chemicals applied as granules. Therefore, they will serve largely as restricted chemical barriers in preventing termite attack rather than as remedial treatments which must spread 6 to 12 inches to achieve termite control.

In field studies in Mississippi in which treated soil is exposed to the elements, 100 percent termite control has been obtained with water emulsions containing 1 percent chlordane for 16 years, 0.5 percent aldrin and dieldrin for 15 years, and with 0.5 percent heptachlor for 12 years. This research indicates that long-term protection of buildings is possible at a very moderate cost.

Another related study indicates that buildings with only the sole plates pressure-treated with wood preservatives or insecticides are not sufficiently protected from damage by termites. Termites can bypass treated members and reach untreated structural and non-structural wood and wood products.

In lab and field studies designed to determine the extent of movement in soil of insecticides applied for termite control, it has been found, by gas chromatographic analyses and bioassays, that little or no movement occurs. Further evidence of stability of chemicals in soils is the fact that 100 percent control of termites is attained after 15 years of severe exposure of the chemicals to the elements.

Promising results have been obtained with continuous water sprays in preventing ambrosia beetle damage to green logs in storage. Effectiveness has been greater than BHC and pentachlorophenol oil sprays presently recommended. If a consistently effective water treatment can be developed, it will be far cheaper and more acceptable to forest industries than present chemical treatments.

b. P. L. 480 Projects

(1)-INDIA

a. Accelerated laboratory investigation on natural resistance of woods to termites. A technique has been developed for the culture in the laboratory of Microcerotermes beesoni, a subterranean carton nest building termite. Testing of samples of untreated wood against Neotermes bosei, a drywood termite, and M. beesoni is now in progress. Also under investigation are factors involved in the longevity of Heterotermes indicola, another subterranean termite, in various species of test timbers, the purpose being to evaluate the chemical causes of natural resistance of certain woods, e.g., toxicity, repellency, and unpalatibility.

6. Survey Techniques

Research on surveys of forest insect and disease outbreaks is currently emphasizing aerial methods using sophisticated instrumentation and techniques. Detection of stands susceptible to insect attack or those undergoing early damage is receiving primary attention. However, research is continuing on design of conventional approaches and improvement of existing methods.

a. Aerial Surveys. In the Southeast, comparative photointerpretation of color aerial transparencies (scale - 1:7920) taken over balsam woolly aphid infested and non-infested Fraser fir stands, provides a technique to follow rates of tree

mortality from year to year. When coupled with aphid population measurements on the ground, an accurate prediction of expected fir mortality one year ahead is entirely feasible.

It has been shown that Ektachrome Special (ASA 64) is the best overall film for aerial photography as a substitute for Super Anscochrome (ASA 100), which was discontinued in 1963. Because it gives superior portrayal of color, greatest range in green hues in the forest, and greatest latitude in exposure with excellent shadow penetration, this film should prove the best for tree species identification on medium- to small-scale photography. However, the characteristics of Anscochrome D-200 make it desirable for low altitude, high speed photography and for detecting off- color foliage caused by insects or disease.

A preliminary photo interpretation test has been completed using 70 mm aerial color film at two scales (1:8000 and 1:1584) to detect ash dieback in the Northeast. Ash was identified with 78 percent accuracy at the smaller scale and 92 percent accuracy at 1:1584. Five dieback classes were correctly interpreted 71 percent of the time at 1:8000 and 88 percent of the time at 1:1584. Hickory was most often mistaken for ash, but others included elm, basswood, sugar maple, and ailanthus. Healthy ash was more difficult to separate from other species than was diseased ash.

A study has been initiated in cooperation with the University of Michigan to determine the feasibility of detecting tree mortality before visual symptoms occur using an array of multispectral detection equipment. Spectral analyses of red pine needles sampled from dying and healthy trees have shown significant shifts in the shape of reflectance curves. A sample of internal needle temperatures revealed that there is a point during the dying process of the tree where needles of a dying tree are as much as two degrees warmer than those of healthy trees. This appears to result from a difference in transpiration rates of the two trees. In regard to the development of an airborne multi-spectral detection system, these preliminary studies indicate that a combination of two or more wavebands, taken simultaneously under varying solar radiation conditions, holds the best possibilities for early detection of a disturbance to a forest environment.

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C. FOREST DISEASES

Problem

Diseases occur in all parts of the country irrespective of land ownership, on all forest tree species, hardwoods and conifers alike. Seeds and seedlings become diseased as do the over-aged giants of the primeval forest. Every part of the tree, from outermost tip of a branch or rootlet to the innermost wood and central pith, is susceptible to disease. Forest plants on forage, recreation, and watershed areas are as subject to attack as those in commercial forests. Tree diseases are caused by biotic entities such as fungi, bacteria and nematodes, or by abiotic factors related to temperature and moisture extremes, air pollution, winds, nutritional excesses or deficiencies, etc. Working singly or in combination, diseases cause death, loss of growth, deformity, lowered quality, or destruction of wood already formed in forest trees. Total losses from disease equal those from other destructive agencies combined. The impact on the volume of wood amounts annually to 5 billion cubic feet of growing stock, including 20 billion board feet of sawtimber--a loss almost equal to the annual cut of timber in the United States. In addition, many disease agents reduce the value of wood products in use by an estimated $300 million per year.

USDA and Cooperative Programs

Both basic and applied research on forest tree diseases are conducted on a continuing long-term basis in the Department. The work is directed toward the solution of disease problems and the development of disease controls. The Forest Service is responsible for the national program now being conducted at 9 of the 10 Regional Forest Experiment Stations, the Forest Disease Laboratory at Beltsville, Maryland, and the Forest Products Laboratory. Each Station conducts research on diseases of major importance within its boundaries and may also have leadership for research on broad regional disease problems. For example, the Intermountain Station has primary responsibility for breeding western white pine for resistance to white pine blister rust, the Pacific Northwest for research on Poria root rot of Douglas-fir, the Lake States on Hypoxylon canker of aspen, the Central States on oak wilt, and the Southeastern for research on forest tree diseases caused by or related to air pollution.

The Forest Service currently devotes 74 man-years of professional effort to research on tree diseases and has technical supervision over another 28 man-years of foreign professional effort devoted to eleven PL-480 projects abroad. Over one-half of the Forest Service scientists working on tree diseases are plant or forest pathologists but to provide all of the talents required to solve our increasingly complex problems we now employ biochemists, ecologists, meteorologists, microbiologists, nematologists, physiologists, serologists and soil scientists.

The program of forest disease research is carried out in cooperation with other Federal, State and local public agencies. The Department of Defense and Department of Navy both support research on the decay of wood in use; TVA and the Universities of California and North Carolina cooperate on the study of air pollutant effect on trees. The Georgia Forest Research Council provides financial aid and several State Forestry agencies provide labor, land, and equipment for research on tree diseases. Through cooperative aid financing the University of Hawaii is conducting studies on seedling diseases; the University of Colorado on the genetics of dwarfmistletoe; Pennsylvania State University on the effect of microclimate on the life cycle of

the fungus Fomes annosus; and Texas A&M on the causes of live oak decline and mortality in east Texas.

A grant under Public Law 85-934 was made to the University of Wisconsin for research on the nature of resistance in eastern white pine to infection by the blister rust fungus. The previous research grants continue: with North Carolina State University (formerly with Yale University) to work on the biochemistry of the wood decay process; and with Duke University to work on the aerobiology of the fungi of Piedmont forests.

Under Public Law 480 the Forest Service has contracted important tree disease research which supplements or complements our domestic program. Projects are currently underway in Poland, Italy, India, Taiwan, Brazil, Columbia, and Uruguay. Another, with Spain, has just been terminated after completion of the study objectives. Some of these foreign studies are designed to disclose native pathogens of special potential threat to North American forest tree species.

Forest industry actively cooperates with the Forest Service in forest disease research. Various companies have furnished land, labor, technical consultation and even financial assistance. Chemical companies have donated products for experimentation and have freely offered advice and technical services to researchers.

The annual outside expenditures for such cooperation are difficult to determine but are estimated to be equivalent to one-half the manpower devoted to tree disease research by the Forest Service.

Progress--USDA and Cooperative Programs

1. Seed and Seedling Diseases

An effective control method has been developed for redcedar blight, the most destructive disease in Great Plains nurseries.

Discovery of a serious dieback and seedling blight of slash pine plantings in Taiwan has major significance for slash pines in this country. American tree species planted abroad are already beginning to yield valuable information for programming disease prevention efforts.

a. Causal organisms. Pathogenicity tests of several clones of Fusarium oxysporum isolated from dead and dying sugar pines show considerable variation in their ability to cause root disease. It now appears necessary to test the pathogenic capabilities of several clones of F. oxysporum to determine the reason for this variation. Microbial assays of the roots of dead and dying coniferous seedlings from several nurseries in California, Oregon, Idaho, and Montana showed similar root disease problems. Macrophomina phaseoli and Fusarium oxysporum were the most common root pathogens.

In Poland, unsterilized oak acorns were sampled at collection and following storage under six different methods. Fifty-one species of fungi were isolated, eight of which are believed to have considerable economic importance. Thirty species of fungi were isolated from unsterilized birch seed stored in suspended jute or paper sacks. Eight of these species were very common, of which six appear to be important in preventing germination (PL-480).

Microflora on seeds of slash, Luchu, Japanese black, Taiwan red, Taiwan white, and horsetail pines were studied. From eight samples, more than 20 genera of fungi were isolated. Among the isolates, Diplodia, Fusarium, Gloeosporium, Pestalotia, Rhizoctonia, and Sphaeropsis were known pathogenic fungi. Of these fungi, Sphaeropsis sp. also infected 5-year-old slash and Taiwan red pine plantations. This disease, a characteristic bud blight, could become epidemic on slash pine (PL-480).

Seedlings showing characteristic damping-off were collected from various nurseries on Taiwan. Seedlings of peacock pine, China fir, slash pine, Luchu pine, and horsetail pine were found to be affected. Inoculations indicated Fusarium, Nectria, Pythium, Rhizoctonia, and Pellicularia rolfsii were responsible for the damping-off (PL-480).

b. Nursery soils and chemical controls. Soil fumigation tests indicate fungi and other soil microorganisms have a significant effect on the ability of Monterey pine seedlings to produce new roots. Pythium spp. were found to play a key role in the failure of seedling roots.

Disease control studies in the nursery at the Institute of Forest Genetics have shown soil fumigation to be an effective control for soil-borne root diseases of white fir seedlings.

Fungicide tests for control of eastern redcedar blight (Phomopsis juniperovora) on seedlings showed that a mercurial fungicide used at the rate of 1, 1½, or 2 pints per 100 gallons of water gave good control and was not improved by addition of spreader stickers. Other fungicides did not provide satisfactory control.

c. Susceptibility of American trees to foreign pathogens. In outplantings of eight important American tree species in Poland, no serious fungus pests have been reported. At present, however some damage by Fusarium sp. and Pestalotia hartgii on eastern white pine, Douglas-fir, Sitka spruce, and lodgepole pine seedlings was observed. More significant losses in the form of non-emergence occurred in species particularly susceptible to drought such as western red cedar, western hemlock, and Sitka spruce.

2. Root Diseases

The very complex area of root diseases, including the interplay of pathogens and beneficial soil organisms, was advanced considerably during the past year. Significant finds: high temperatures may play an important part in decreasing survival of Fomes annosus in stumps; the relatively harmless fungus Peniophora gigantica can replace F. annosus in stumps even though initial infection by the pathogen is heavy; evidence mounts that mycorrhizae are active in several ways to reduce or prevent root infections by soil-borne pathogens.

a. Fomes annosus root rot. The incidence of Fomes annosus infection is very significantly related to low organic matter, high Ph, low silt content, high clay content, and sparse grass cover. An equation for predicting high hazard sites may be possible.

The influence of temperature on infection by conidia and basidiospores and on actively growing mycelia of Fomes annosus was determined on freshly cut non-sterilized bolts and surface-sterilized bolts of loblolly pine. F. annosus was recovered from non-sterilized bolts incubated at temperatures from 5° to 30° C, but not at 35° and 40° C; whereas from the surface-sterilized bolts, the fungus was recovered at all temperatures except 40° C. Growth of Trichoderma viride, Aspergillus niger, and

Penicillium spp. covered the surface of non-sterilized bolts. Suppression of F. annosus by other fungi at 35° C, and its death at 40° C, indicates that high temperatures may play an important part in survival of F. annosus in stumps.

In studies of the aerobioloby of fungi of Piedmont forests major and consistent components of summer air were Fomes annosus, Peniophora gigantea, Trichoderma viride, and species of Alternaria, Aspergillus, Ceratocysis, Curvularia, Penicillium, Pullularia and Pestalotia. Bald cypress stem tissue proved to be highly selective for F. annosus. Pretreatment of fresh conifer stem tissue with 1 percent orthophenyl-phenol markedly increased annosus colonization and detection efficiency.

Two years after replanting the site of a white pine stand clearcut becuase of heavy losses from Fomes annosus, the fungus was isolated from 28-58 percent of dead white, Virginia, Scotch, and shortleaf pines examined. Mortality from F. annosus up to 3 percent was found in recently established slash and loblolly plantations previously occupied by pine plantations or mixed pine-hardwood stands in South Carolina and north Florida. These studies indicate that annosus root rot must be considered a serious problem in young stands planted on former forest land.

The growth of Fomes annosus in roots of naturally infected loblolly pine stumps was related to the colonization of these roots by other fungi entering through the stump surface. Two months after cutting in October, 63 percent of the stumps examined were infected with F. annosus. After 10 months the fungus was present in 58 percent of the roots examined. At the same time, Peniophora gigantea, which had also entered from the stump, was found in 20 percent of the roots. Two months later almost half the roots examined contained P. gigantea while the number with F. annosus had dropped to 23 percent. P. gigantea apparently was important in replacing F. annosus in stumps, even though initial stump infection by F. annosus was heavy.

Inoculation of shortleaf pine stumps with conidia, mycelium in sawdust, or basidiospores of Fomes annosus resulted in over 90 percent infection. In the basidiospore and mycelium series, growth rate increased with time during the first nine months subsequent to inoculation, growing 0.9 inch per month for the first 3 months, 2.7 inches per month for the second 3 months, and 5.8 inches per month for the last 3-month period. Stump colonization and rate of growth was greatest when basidiospores were used as inoculum and inoculations with 140 viable basidiospores per ml. resulted in greater stump colonization than using 86,000 viable conidia per ml.

Decay resistance of sapwood from roots and stems of eight coniferous species was determined in a complete factorial experiment using 16 tissue isolates of Fomes annosus from the same eight species. Average weight loss of test blocks due to decay was measured after 12 weeks in soil-block chambers. Among the wood species tested, Juniperus virginiana was most resistant, Pinus resinosa, P. virginiana, and P. palustris were intermediate; and P. palustris var. elliottii, P. strobus, and P. taeda were least resistant. Stemwood of all species was more resistant than root wood. In further studies of the influence of temperature on Fomes annosus, it was found that actively growing mycelium in wood was killed when exposed to a temperature of 40° C. for two hours. Conidia of F. annosus, when tested in liquid malt extract and on wood blocks were killed in one hour at 45° C. Basidiospores in liquid malt extract and on wood blocks, were killed in 30 minutes at 45° C. Preliminary data indicated that in North Carolina stump surface temperatures reached 40° C.or higher for periods of at least two hours on more than 50 percent of the days from May to August. These data provide one reason why less stump colonization by F. annosus occurs in parts of the southeastern United States during summer than during other seasons.

Studies of natural colonization of stumps by various microorganisms and their relation to infection and spread indicated that F. annosus is blocked from spreading underground by invasion of the roots by such soil microorganisms as bacteria, blue stain fungi, Trichoderma viride, and Fusarium spp. after death of the root cambium.

Fomes annosus has continued to spread in two of five study plots established in 1959 in thinned slash pine plantations in the Southeast. However, only one new infected tree was found in each of these two plots during the last observation period. Infected and dead trees in these five 0.1-acre plots now include 51, 47, 31, and 13 percent of the original stand compared to 22, 5, 22, 15, and 13 percent, respectively, of the dead and infected trees present in 1959.

Seven chemicals were tested in a shortleaf pine plantation in southern Missouri to determine their effectiveness in preventing colonization of stumps of freshly-cut trees by Fomes annosus. Of the materials tested, urea, ammate, ammonium fluoride, borax, creosote, and pentachlorophenol, all reduced colonization when compared with controls. However, urea, ammate, ammonium fluoride, and borate compounds were more effective than creosote or pentachlorophenol.

Methods of isolating fungi from soil, rhizosphere, roots, and stumps have been developed in Poland. Populations of fungi isolated from soil of pine stands attacked by Fomes annosus and from stands in which F. annosus was not present, were different but showed no correlation with the absence of F. annosus in the stand (PL-480).

Freshly cut discs of sound pine stems inoculated with a spore suspension of Trichoderma album appeared fully protected against infection by Fomes annosus (PL-480).

b. Other root pathogens. Slash pine wilt caused by Pythium sp. was found in one six-year-old plantation on Taiwan. Symptoms appeared as yellowing of the needles and early defoliation. Brown lesions appeared on the roots and were frequently covered with white mycelial mats. Application of organic mercurials, such as 0.05 percent granosan, 4-6 liters/square meter gave good control (PL-480).

Phytophthora heveae, previously unreported from North America, was isolated from soil under old-growth hardwood stands in eastern Tennessee and western North Carolina.

Studies on morphology of sexual and asexual structures and physiological comparisons consisting of growth rates, sporangial production, and colony development on solid media, were made with isolates of mating types of Phytopthora cinnamomi. Certain characters exhibited a wider range in variability than previously reported, although the total range is confined within and among the isolates used.

In Poland, it has been found that the quantity of soil fungi antagonistic to Armillaria mellea was significantly higher in spruce stands not attacked by A. mellea than in those attacked (PL-480).

c. Soil microbiology. The influence on microbial activity of red-alder and Douglas-fir sawdust added to soil depends on particle size: the smaller the particle, the faster its oxidation. This relationship may be due to the smaller particles' larger surface area in relation to volume and the greater rupturing of lignin-cellulose bonds during their mechanical preparation. Addition of ammonium nitrate to sawdust did not stimulate oxygen uptake of samples, possibly because the microbes were relieved from the necessity of decomposing nitrogenous organic matter to meet their nitrogen requirements.

d. Mycorrhizae. Evidence continues to substantiate earlier theories that mycorrhizae protect trees from disease. Mycorrhizal fungi that mantle rootlets of most species of economically important forest trees, may protect the rootlets from pathogenic infection by secreting antibiotics, providing a physical barrier to infection, reducing attractiveness to pathogens by using rootlets' surplus carbohydrates, and fostering populations of protective rhizosphere organisms.

On Douglas-fir, three types of mycorrhizae, each formed with a different fungus, were compared for rhizosphere populations of bacteria, molds, and Streptomyces to evaluate the extent to which kinds of mycorrhizal fungi may differ in protecting tree rootlets against root disease. The rhizosphere microorganisms differed both in kind and number between types of mycorrhizae, indicating that species of mycorrhizal fungi could therefore vary markedly in their effects on root pathogens as well.

There is evidence that communities of mycorrhizal fungi within a relatively small area and even on roots of a single tree are very complex. Of 1,600 mycorrhizae cultured, 213 yielded pure cultures of fungal symbionts. Several mycorrhizae produced two or more fungus species. Roots from one seedling yielded seven different fungi.

Mycorrhizae developed well on slash pine with pure cultures stabilized at $_{p}H$'s from 4.0 to 6.6 although best development occurred in less acid substrates. Stimulation of seedling growth differed between species of mycorrhizal fungi inoculated; a fungus species-$_{p}H$ interaction was also apparent, indicating that not all mycorrhizal fungi affect seedlings the same way in a given soil and that a given fungus may affect seedlings differently in different soils.

A tuberculate mycorrhizae of Douglas-fir is formed commonly in western coastal states and British Columbia by a white Basidiomycete that infects a rootlet to form a compact, prolifically-branched ectotrophic mycorrhiza in combination with a Phycomycete that sheaths the aggregate of mycorrhizal tips. The significance of this phenomenon is unknown at present.

Twelve cultures were obtained from sporophores of suspected mycorrhizal-forming fungi using spore cast and tissue plant techniques. Isolations from 729 mycorrhizal root tips produced 525 cultures other than common contaminants. First synthesis trials showed that portions of a fungal mantle were formed on ponderosa pine seedlings grown with cultures from Hypomyces lactifluorum.

A study of the anatomy of sugar maple rootlets and an associated mycorrhizal fungus has been completed. In addition to basic anatomical information, evidence indicates the fungus found free of rootlets in the soil may have originated within rootlet cells and is released following death and disintegration of rootlet tissue.

e. Nematodes. Root lesion nematodes, Pratylenchus penetrans, in roots of eastern redcedar transplants were killed when roots were exposed to hot water at 52° C for two minutes; greenhouse survival of plants receiving this treatment was high.

A total of 311 soil samples was collected under shortleaf, slash, loblolly, longleaf, eastern white, Virginia, and South Florida slash pines, in 7 southern states. Dagger nematodes, Xiphinema spp., were recovered from 65.3 percent of all the samples; it was the most frequently found genus associated with pines. The other common genera of plant-parasitic forms were ring, Criconemoides spp. (35.4 percent), spiral, Helicotylenclus spp. (34.4 percent), sheath, Hemicycliophora spp. (33.4 percent), and lance, Hoplolaimus spp. (19.9 percent). The cystoid nematode, Meloidodera spp.,

a known pathogen of slash and loblolly pine was associated with all pine species, but was recovered in less than 20 percent of the samples from any one species.

At the end of the second season of field nematocidal fumigation tests, it was found that height growth of trees in methyl bromide-fumigated plots was significantly greater than that in 1,3 dichloropropene and 1,2 dichloropropane (D-D fumigated) and non-fumigated plots. Average heights of trees in D-D fumigated plots were superior to those in non-fumigated plots. It was also shown that regardless of nursery treatment, fumigation of the outplanting site resulted in increased growth. At the end of the fifth growing season, the same plant parasitic species (pine cystoid, lance, spiral, and American dagger) that were predominant prior to fumigation when the test was begun, were still present. Populations of lance nematodes increased during the past four years in all plots except those receiving no chemical treatment in the nursery or outplanting site. In non-fumigated plots, populations of pine cystoid nematodes decreased and spiral nematode populations increased in all plots except those treated with methyl bromide. At the end of the fifth growing season, significant differences in growth between trees growing in fumigated plots and those in non-fumigated plots were still evident.

The root knot nematode was found for the first time parasitizing roots of mature ponderosa pine.

3. Stem Diseases

Progress has been made in clarifying the taxonomy and host relationships of the dwarfmistletoe genus, Arceuthobium, and in differentiating between morphologically similar Cronartium rusts of pine, using two techniques--aeciospore germination characteristics and serological reactions. Solution of a baffling disease in red and jack pine plantations in the Lake States appears to be imminent with the discovery of an introduced pathogen associated with it.

a. Native rusts of conifers. Most races of Peridermium filamentosum, including "Inyo Peridermium," in Utah, Nevada, and California do not infect Scrophulariaceae and produce distinctive, short aeciospore germ tubes. A single collection of P. filamentosum from Arizona infected Scrophulariaceae and produced the long aeciospore germ tubes characteristic of Cronartium. This morphological distinction, if it holds true for additional heteroecious collections, will simplify and speed life cycle tests.

Intensive herbarium studies clarified records, distributions, and hosts of Peridermium filamentosum and P. stalactiforme. The former, including the barely distinguishable "Inyo Peridermium," occurs not only on Pinus ponderosa var. scopulorum, but also on varieties arizonica and ponderosa, Pinus jeffreyi, and Pinus engelmannii. Peridermium stalactiforme causes limb rust on Pinus jeffreyi and cankers on several other pine species. It occurs in California Coast Ranges where P. filamentosum had been reported, but no coastal specimens of the latter were seen.

Telia of Cronartium comandrae germinate only in saturated atmospheres at temperatures from slightly above freezing to about 24° C; however, good germination is limited to a range from about 10 to 23° C. Germination begins after about 6 hours under good conditions and continues for about 15 more hours. Each telium can produce from 100 to 1500 basidiospores.

Study of tissue sections shows that Cronartium comandrae mycelium spreads first in phloem near the cambium in pine cankers; growth in other parts of the live bark and

between the outermost cells of the wood comes later. Parenchyma cells in the inner bark enlarge and the bark swells. Few new sieve cells are formed and many cells are crushed by abnormal growth of parenchyma. Rays infected at the cambium become wider than normal and with tree increment become buried in the wood leaving a permanent marker of when they first became infected. Centripetal growth in wood extends less than 1 mm. from the swollen rays.

Southern cone rust is the most damaging disease affecting slash pine cones and seeds, and its impact on seed orchards and production areas can be serious. Female strobili are susceptible to infection from the time of emergence through the pollination stage. Hydraulic spray coverage with Ferbam at 5-day intervals during this period gives good protection against this disease.

A method has been developed to differentiate Cronartium quercuum and Cronartium coleosporioides on the basis of aeciospore germ tube characteristics.

Lodgepole pine and its hybrids have been found to be more susceptible to sweetfern rust and Eastern gall rust than jack pine.

b. White pine blister rust. Fungicide tests have been underway since 1959 in an attempt to eradicate white pine blister rust from infected sugar pine. Conventional fungicides have been as effective as antibiotics when sprayed directly on infected tissue. As yet there is little evidence of effective systemic action of any chemicals tested.

Further examination of studies with basal spray applications of antibiotic fungicides indicate these chemicals are not effective in controlling blister rust on sugar pine.

In using cycloheximide in the control of white pine blister rust, it was found that the proper concentration of the antibiotic in the spray mixture is important and that any water present will remove it from the spray mixture. It is therefore necessary that all mixing tanks, sprayers, bases, and other mixture containers be kept free of water and that tree surfaces be dry before application.

In the Lake States, preliminary results three growing seasons after treatment of blister-rust infected white pine with antibiotics, do not indicate effective translocation although bioassays show that the antibiotics do move through the tree and persist for at least one year. Direct treatment of cankers does inhibit canker growth but apparently does not completely eradicate infection unless supplemented with scarification and possibly special carriers such as lanolin.

Discovery of a new infection on limber pine extends the known range of Cronartium ribicola to within 33 miles of Utah, indicating that an increasing acreage of whitebark and limber pines will be killed by the disease unless control measures are undertaken.

Though further research will be required, induced mutation of western white pine with ethyl methanesulfonate holds considerable promise as a means for improving resistance to white pine blister rust.

Successive progeny tests continue to show that about one in four wild, canker-free western white pine "candidate" trees has high resistance breeding value for white pine blister rust.

Comparative biochemical analyses of blister rust resistant and susceptible trees have so far failed to reveal differences suitable for use as selection or screening tools. Levels of glucose and certain glucose-associated phenolics vary with resistance, but environmental effects in the material at hand complicate analyses for these substances.

Preliminary results indicate that mixed-pollen crosses may be satisfactory for determining combining ability of new selections.

Preliminary results on blister rust resistance of F_1 seedlings backcrossed on one of the "wild" parents show resistance of backcross progenies above that of F_1's. This is the first good evidence that selection may result in near the predicted, per-generation gain in resistance.

Successful "wet pollinations" with Pinus monticola pollens held in water suspensions up to 24 hours suggest the feasibility of treating pollen with water soluble chemical mutagens immediately before pollination.

Thermal night breezes were found to be very important in local and long-distance spread of blister rust spores.

Further evidence of races of blister rust on wild currant was found with discovery of a spore collection from New Hampshire that is unable to infect a currant species used as a differential.

A sequential sampling plan has been devised for estimating the Ribes spp. population on blister rust control areas in California. This new sampling scheme gives information about the size of the residual Ribes population comparable to that given by the present most powerful field method and at about half the cost. A fortran computer (7094) program has been written and tested which will permit data from other regions to be used in calculating a sequential plan appropriate to their local conditions.

c. Fusiform rust. Teliospores and urediospores of fusiform rust usually are produced on oak leaves; however, they have now been found on young stem tissues of the oak host.

Lower chain fatty acids significantly increase the metabolism of the fusiform rust fungus. It may be possible to increase the proportion of these acids in pines with sporulating galls, thus exhausting the spores, or to decrease the acids in the oak hosts to reduce or limit infection.

Three species of Cronartium rusts were compared serologically using antigen-antibody reactions in rabbits. Each of the three species proved to be serologically distinct, including C. fusiforme and C. cerebrum which are indistinguishable morphologically.

Viability of Cronartium fusiforme aeciospores was maintained up to 12 months by dessication, vacuum drying, and vacuum storage at 5° C. Germination studies showed need for rehydration of dried spores before inoculation. Moisture uptake in dehydrated spores occurred almost entirely during the first 6 hours of rehydration. In vitro germination temperature limits appeared to be 5° and 30° C. with an optimum of 20° C.

The period of water oak leaf susceptibility was defined under controlled greenhouse conditions. Leaves older than 18 days rarely became infected by aeciospores. Leaves older than 12 days primarily bore telia, whereas leaves up to 12 days of age first bore uredia which were later replaced by telia.

Both the processes of leaf resistance and telial replacement of uredia progressed in a pattern beginning at the leaf base and proceeding to the leaf tip.

Loblolly and slash pine seedlings were successfully inoculated with secondary and tertiary sporidia. Indirect germination by primary sporidia was noted on substrata not suitable for infection, e.g., hardened slash pine needles and oak leaves. Thus, the sporidium functions both as an organ of infection as well as one of reproduction.

Acetates and bicarbonates inhibit the germination of fusiform rust spores, even in the presence of otherwise stimulatory compounds. These may become the bases for cheap and effective protectant fungicides.

Cycloheximide was tested in a range of different concentrations for control of blister rust on eastern white pine in the Southeast. Data taken over a 5-year period following infection showed that no control was being obtained with this antibiotic.

Spraying for fusiform rust control in nurseries is most effective if done when telia are producing spores. Telia are significantly more numerous in the lower 6 feet of the oak crowns; therefore, the need for spraying can be determined quickly and with a high degree of confidence.

d. Canker diseases. A new canker disease of western larch caused by Phomopis pseudotsugae was reported in the western United States. Infected trees are killed or damaged to the extent they lose all economic value as a unit of a stand. Douglas-fir is known to be susceptible to this disease when planted in England as an exotic.

A basal canker on 2 to 3-year-old cottonwood trees in Mississippi infected 21 percent of the trees in May 1963; and an additional 2 percent were diseased by July. Three fungi, Cytospora chrysosperma, Phomopsis macrospora, and a Nectria sp. were isolated from these trees; however, the importance of these organisms has not been determined.

As part of a long-range effort to control chestnut blight, several hybrid chestnuts and a promising Chinese chestnut introduction were grown in 15 cooperative test plots. When compared for blight resistance and growth characteristics 9 to 17 years after planting, all 15 plots contained some promising trees.

Hundreds of surviving American chestnut trees have been tested for resistance to the chestnut blight fungus with little success. Thousands of hybrids produced in breeding programs have yielded about 3 percent with some degree of blight resistance, rapid growth, and forest tree form. Treatments with colchicine and irradiation are being tried to produce a resistant mutant of American chestnut.

Annual cankers on red and sugar maples were found to be the result of several different species of fungi invading wounds made by the teeth of red squirrels.

In a survey of aspen cankers in 5 National Forests of Colorado, sooty-bark canker, considered the most damaging in aspen stands, was found in 94 percent of the plots, on 2 percent of the living trees, and on 51 percent of the dead trees. Cytospora

canker, black canker, and a "nectria-like" canker were found throughout the stands. A few hypoxylon cankers were found; however, the status of this disease in Colorado remains questionable.

An apparent correlation exists between the average annual rainfall and mean July temperatures and the prevalence of hypoxylon canker. This relationship is based upon climatic data from regional maps and canker distribution data from field plots.

Preliminary results from over 500 inoculations of aspen with various isolates of Ceratocystis from aspen, sycamore, and sweet potato indicate that incipient cankers are formed four months after inoculation and that typical cankers are evident after one year.

The southern limit of hypoxylon canker on aspen was extended to within 200 miles of the Mexican border by the discovery of a canker on a living aspen near Big Lake, Apache National Forest, Arizona.

Cytospora canker (caused by C. kunzei) of Douglas-fir was prevalent in the Pike National Forest and also occasionally as far north as the Roosevelt National Forest on the eastern slope of the Rocky Mountains in Colorado. This outbreak is evidently associated with decreased precipitation along the eastern slope during the past two growing seasons.

Scleroderris lagerbergii, a serious pathogen in Western Europe, has been isolated from several red and jack pine plantations in northern Michigan. Evidence indicates this fungus is responsible for the "Jones disease" problem in Michigan plantations.

An apparent correlation exists between the average annual rainfall and mean July temperatures and the prevalence of hypoxylon canker in the Lake States.

Winter sunscald resulting in either cankers or frost cracks has been observed on a large proportion of the stems in several second-growth northern hardwood stands in northern Wisconsin. Dissection of affected trees showed that the sunscalds occurred during the winter of 1935-36, about 10-15 years after the first commercial clear cutting of the stands. Observations indicate some such wounds are kept open by either fungi or perhaps insects and result in large elongate cankers; other wounds callus over but frost cracks later serve as entry courts for decay and/or discoloring fungi that eventually cause considerable degradation and mortality through wind breakage.

e. Dwarfmistletoes. Dwarfmistletoes parasitize and seriously damage most native western conifers. Their control has been possible only by expensive silvicultural methods. Forest managers have long sought a safe effective chemical method of controlling this parasite and since 1959 the Pacific Southwest Station has been concentrating on a study of prospective formulations. An isooctyl ester of 2, 4, 5-trichloro-phenoxylbutyric acid is one of the most promising chemicals found.

Colletotrichum gloeosporioides previously thought to infect only the true fir form of dwarfmistletoe, Arceuthobium campylopodum f. abietinum, was also found to infect A. campylopodum f. typicum and A. americanum. Studies suggest that geographically distinct isolates of the fungus exist and no perfect stage for long-distance spread occurs since isolates on a given host in a particular area retain their distinctive characters.

Analyses of 10-year basal area growth of dwarfmistletoe-infected ponderosa pine in northern Arizona and southern New Mexico indicate basal area growth was reduced slightly in trees only slightly infected and decreased rapidly with increasing degree of infection. Mortality in the heavily infected class offset growth thus resulting in a negative basal area increment.

Investigations of dwarfmistletoe spread and buildup from overstory infection of 22-year-old plantation trees indicate that approximately 16 percent of the trees within 100 feet of the overstory were infected, the percentage of trees infected increased with height (vigor) of the tree, and the percentage of trees infected was not markedly different from 0-90 feet from the overstory infection.

As part of a continuing study toward a taxonomic revision of the genus Arceuthobium, it was learned that (1) A. campylopodum f. tsugensis was found on species of fir and pine in addition to the hemlocks (Tsuga heterophylla and T. mertensiana); (2) there are apparently two hard pine forms of the A. campylopodum complex in California which seem to differ in morphology and phenology, as well as in host relationships; (3) the rare Brewer spruce is severely parasitized by the fir mistletoe in at least one locality in southern Oregon; and (4) the hosts and geographic ranges of several other dwarfmistletoes were clarified.

Specimens of Arceuthobium were examined in herbaria of the Universities of Arizona, California, and Washington, Pomona and Claremont Colleges, Stanford University and U. S. Forest Service collections at Portland, Oregon, and Berkeley, California. Collections and exchanges added nearly 300 specimens to the mistletoe herbarium at Fort Collins, Colorado.

Cytological examinations of most of the North American species of the genus Arceuthobium indicate that all members of the genus are diploids with a basic chromosome number of 14, the same as that in the related leafy mistletoes (Phoradendron).

Initial velocities of dwarfmistletoe seeds immediately after expulsion from the fruit were measured by use of a high-speed photographic technique. The initial velocity of four species studied averaged 2400 cm/sec. (78 ft./sec.).

f. Heart rots. Decay did not advance significantly after 2 years in willow and Nuttall oaks inoculated with pure cultures of Poria ambigua, Polyporus fissilis, and Polyporus hispidus. Most inoculation wounds healed after 2 years. Over a 10-year period, there were no significant differences in spread between the three fungi. Tree-to-tree differences were large. Cankers of P. hispidus had formed on 29 percent of the trees cut 2 years after inoculation.

In stands of black willow on the batture of the lower Mississippi River, the proportion of volume rendered cull by rot increased with stand age, but was less than 1 percent after 30 years, by which time most pure stands were breaking up.

In the study of decay in hardwoods, trees on 40 fifth-acre plots in Ohio and 37 fifth-acre plots in Kentucky have been cut, dissected, sound and cull volumes measured, and decay organisms isolated. Thirty-seven different species of fungi have been identified to date. Of these, two species (Stereum frustulatum and S. gausapatum) accounted for over one-third of the decay. It was found that almost 40 percent of decay fungi enter through fire scars.

Field investigations of heartrots in Central States hardwoods have shown that some decay columns become inactive when infection courts such as fire scars heal over, leading to the supposition that oxygen and CO_2 tensions may play a significant role in rates of decay. Laboratory tests with Stereum gausapatum and S. frustulatum show a close correlation of growth with oxygen and CO_2 concentration. Oxygen and CO_2 relationships of decay columns in the field will be determined by means of a portable Oxygen analyzer.

In an extensive study of the organisms associated with decays and discolorations in northern hardwoods, bacteria were isolated more frequently than fungi. The fungi and bacteria often were associated with each other and with specific zones of decay and discoloration. The principal bacterium was similar to species of Erwinia. Other commonly found groups were tentatively identified as Pseudomonas, Xanthomonas, and Bacillus. Because of their close association, both fungi and bacteria are believed involved in decay and discoloration of living trees.

A possible explanation is suggested for basal cracks and decay in white and yellow birches observed commonly in the eastern slopes of the White Mountains. Observation and isolation revealed that Armillaria mellea was associated with a root rot of affected trees. The root rot is usually followed by cracking at the base, and other decay fungi then enter the cracks.

Phialophora melinii and Cytospora decipiens were two of the principal fungi isolated from stained and decayed wood of northern hardwoods. In agar culture medium, pigmentation by these fungi increased as the ratio of carbon to nitrogen source was increased. In a liquid medium, pigmentation was strong only when certain microelements were added. P. melinii produced pigment when either Fe, Sn, Mn, or Ca were added, but C. decipiens produced pigment only in an Mn-amended medium.

In northern hardwood decay studies blackened areas on the trunks of sugar maple were caused by a fungus complex growing saprophytically on the bark surface following wounding by various agents, such as sapsuckers, and the release of large quantities of sap. Sapsucker attacks are concentrated almost exclusively on black-barked trees. The black bark can be used as an indicator of possible bird peck defect in maple.

4. Foliage Diseases

A major contribution in the study of foliage diseases was the presentation of conclusive evidence to show that chlorotic dwarf in white pine is caused by an atmospheric pollutant acting on the foliage of susceptible individuals. In Italy, the proved susceptibility of Douglas-fir, 6 species of North American pines, and 11 foreign pines to the pine twist rust emphasized the need to exclude the fungus pathogen from this country.

a. Chlorotic dwarf of eastern white pine. Although chlorotic dwarf symptoms on eastern white pine suggest a virus infection, no viral transmission has been demonstrated after 6 years from root and shoot grafts made between diseased and healthy trees. Evidence indicates that susceptibility to chlorotic dwarf is genetically controlled and the disease apparently results from a causal agent acting directly upon the foliage rather than the root system of the tree. The appearance of another needle blight, emergence tip burn, on some but not all chlorotic dwarf trees and on many healthy pines in the experimental plots inferred that susceptibility to each disease is independent of the other.

In 1960, six long-term chlorotic dwarf plots were established in 5-year-old plantations to appraise the effects of annual application of complete fertilizer, over a period of 5 years, on the growth and symptom responses of diseased white pine. For the past 5 years all fertilized trees have continued to exhibit typical symptoms of chlorotic dwarf.

Six other permanent plots were established in Ohio for study of spread, disease intensification and symptomatology of chlorotic dwarf in plantations. After 5 years of periodic observations, no intensification in disease symptoms has occurred on most trees. There was no indication of disease spread within plots.

Conclusive experimental evidence has now been obtained to show that chlorotic dwarf is caused by an atmospheric pollutant acting upon the foliage of susceptible white pines. Studies utilizing filtered air in plastic chambers over tree crowns have been undertaken to define the nature of these air pollutants.

In 1964 another study was initiated to obtain further information on how various atmospheric environments would affect healthy and susceptible white pines. Groups of chlorotic dwarf pines were indexed for disease severity and transplanted to areas with known sources of pollution. Trends in reactions thus far indicate that air pollutants are the primary causal agent.

Protective sprays applied to some commercial crops have been reported to reduce damage from air pollutants, particularly damage from ozone. But, treatment of chlorotic dwarf trees with weekly applications of some of these compounds failed to prevent the development of needle symptoms on newly emerging foliage in preliminary trials.

b. Emergence tipburn of eastern white pine. Eastern white pine has been used to detect air-borne phytotoxicants in at least two instances: first, low oxidant concentrations causing emergence tipburn in remote areas, and second, air pollution associated with coal-burning power plants. Eastern white pine may be used as a quantitative and qualitative biological indicator of such gases or gas mixtures as sulfur dioxide, chlorine, ozone, and automobile exhaust.

Continuous recordings of oxidant concentrations were made in valleys and on a mountain top in southern Appalachian forests. The diurnal variations in the valleys were such that the highest concentrations occurred during the day, with the highest average concentrations at 2:00 p.m. By contrast, however, highest oxidant concentrations on the mountain top occurred at night with the highest average concentration occurring at 5:00 a.m. Upward displacement of ozone-rich air by formation of temperature inversions is suggested as a possible explanation for the differences in diurnal fluctuations between valley and mountain-top conditions.

c. Eastern red cedar blight. Survival of non-blighted Juniperus virginiana stock was significantly higher than blighted (Phomopsis juniperovora) stock at the end of each of five growing seasons, however, there were no differences in height or stem diameter in the surviving blighted and non-blighted trees at the end of the third, fourth, and fifth growing season.

d. Needle casts. Several new Colorado host-fungus records were established in a survey of coniferous foliage diseases. The only widespread disease organism observed in 1963 was Hypodermella concolor on lodgepole pine.

A new species, Lophodermium ponderosa, was described as being capable of causing serious injury to ponderosa pine, but was not widespread in 1963. This fungus has many gross characteristics that would place it with the genus Hypodermella, but spore characteristics indicate its placement in Lophodermium. The fact that an unusually distinct species has till now escaped description suggests it is either restricted in range or it seldom fruits. The new fungus may stimulate important revisions of taxonomic concepts within the Hypodermataceae.

Inoculations of Pinus flexilis with Hypodermella arcuata showed that the technique employed apparently allowed infection to occur. Pathogenicity and relative susceptibility of the foliage of different ages to infection were not definitely established, but more extensive use of the inoculation technique employing artificially moistened cheesecloth bags seems justified.

Hypodermella cerina on ponderosa pine and Nothophacidium abietinellum on Abies lasiocarpa were established as new needle cast fungus records in Colorado.

Pine needle cast caused by Lophodermium pinastri was found at altitudes from 50-2150 feet on Taiwan. A Pestalotia sp. was also found to be pathogenic on needles of Luchu, Japanese black, and slash pine (PL-480).

d. Pine twist rust. Seedlings of Douglas-fir and 6 species of North American pines (Pinus taeda, P. elliottii, P. ponderosa, P. banksiana, P. contorta, and P. resinosa) have been proved susceptible to pine twist rust in a study in Italy. Eleven foreign pines, including a white pine, and European larch are also susceptible. Potential hosts for this destructive disease include our valuable hard pines, white pines, larch, and Douglas-fir. Our widely distributed aspens and poplars can serve as alternate hosts, indicating the need to exclude this pathogen (PL-480).

e. Miscellaneous. The life history of the form of Coleosporium asterum that infects red pine has been described. Three forms within the species with different host ranges are recognized.

Dothistroma pini, causing needle blight of Austrian pine, may be controlled by Bordeaux mixture.

Inoculations of healthy current year foliage of lodgepole pine with Neopeckia coulteri showed that this fungus is a strong pathogen capable of killing vigorous, recently formed foliage.

One application of the semicarbazone derivative of cyclohexamide at 50 ppm produced significant control of brown spot needle blight on longleaf pine, but residual action did not last more than 3 months.

Spores of the brown spot needle blight fungus of longleaf pine were inhibited but not killed when cyclohexamide was added to germination media.

Anthracnose of China fir was found to be causing serious damage in the central part of Taiwan. The disease is probably caused by Gloesporium sp., however, the ecology of the disease has not been worked out completely. (PL-480).

5. Systemic Diseases

Good progress was made in oak wilt research with a partial explanation for the low rate of overland spread; development of a fumigation technique for oak wilt infected logs to render them safe for foreign shipment; and completion of tests of virulence of the oak wilt fungus following maintenance on artificial media for 13 years.

a. Oak wilt. Sub-cultures of isolates of the oak wilt fungus which had been maintained solely on artificial media for up to 13 years were used to inoculate various oak species. The high percentage of infections obtained and the time of appearance of initial wilt symptoms indicated that there was little loss of virulence in any of the isolates used.

In a study of effect of inoculum spore load and inoculation site on incubation period and symptom expression, black oaks were inoculated in either the bole or a lateral branch with one of six spore dosages of the oak wilt fungus. Trees inoculated in the bole with the heaviest spore load had a shorter disease incubation period (4 weeks). Ninety-six percent of the trees that became diseased developed symptoms during the same growing season in which they were inoculated, the remaining 4 percent during the following season. Insect vectors of this disease would likely introduce relatively few spores into healthy trees. The low percentage of successful inoculations with low spore dosages in this study suggests at least a partial explanation for the low rate of overland spread of oak wilt.

Amino acids and sugars from the vascular fluid of oak wilt infected and uninfected oak trees have been separated by paper chromatography. The vascular fluid from wilt infected oaks, in general, yields larger amounts of ninhydrin-reacting compounds. High concentrations of sucrose, glucose, and fructose have been found more consistently in diseased than in healthy trees.

The results of a cooperative study appraising the effectiveness of oak wilt control programs and methods in Kentucky, North Carolina, Tennessee, Pennsylvania, and West Virginia have been analyzed. Oak wilt spread was reduced by 14 percent in Kentucky, 42 percent in North Carolina-Tennessee, 50 percent in West Virginia, and 76 percent in Pennsylvania. Evidence was obtained suggesting that the present relatively low rate of oak wilt spread would not increase even without control in Kentucky, North Carolina and Tennessee. Conversely, the results indicate that the rate of disease spread would increase appreciably in Pennsylvania and West Virginia without the counteracting effects of the control programs. It was shown that new single-tree infection centers are more subject to control than older centers consisting of two or more diseased trees, pointing to the importance of an effective system of detection. The pattern of uncontrolled oak wilt spread was shown to be characterized by a preponderance of short distance spread, i.e, within 50 feet of sources of inoculum, and relatively infrequent spread over greater distance.

Several countries will not accept oak logs for import if they originate within the known range of oak wilt in the United States. Efforts to render logs safe show that exposure of infected logs to a 30-pound-per-1000 cubic feet concentration of methyl bromide at 65° F for 7 days is an effective treatment.

b. Miscellaneous. The occurrence of dead and dying pines near several electric substations in south Mississippi has been reported. Biotic factors do not appear to be involved. Investigations to explain this problem are continuing.

Sapstreak, a killing disease of sugar maple previously reported from the Southeast and the Lake States, was found in Vermont for the first time.

A survey for ash dieback in New Hampshire, Vermont, Massachusetts, Connecticut, New Jersey, and Pennsylvania during the summer of 1963 revealed that 27.2 percent of the ash were dead or dying, and of these 8.9 percent were dead. All other hardwoods were classified as 23.2 percent dying and dead, and of these 6.7 percent were dead.

Declining and dying Quercus rubra and Q. coccinea in the Northeast were found to be affected by leaf roller defoliation, root rot, Agrilus attack, late spring frost, drought, and unfavorable soils. Symptoms of decline were reproduced artificially by defoliation of sapling Q. rubra.

A dieback survey of yellow birch, sugar maple, red maple, and beech was conducted in a managed, old-growth forest in Upper Michigan from 1948 through 1964. Very few trees died, but many exhibited varying amounts of dieback. Yellow birch was injured most severely, followed by beech, red maple, and sugar maple in that order. Dieback increased from 1958 to 1962, followed by a recovery trend in 1963 and 1964. Examination of records kept for other purposes since the late 1920's indicated that some trees have undergone three such cycles of dieback and recovery. The evidence suggests that the cause is environmental. Prolonged high water tables in early spring resulting in rootlet mortality and associated dieback appear to offer the best explanation at present.

A study on the effect of the sapstreak disease of sugar maple on log and lumber values is in progress. Preliminary results indicate that log and lumber values, based on current prices, are reduced by about 40 and 60 percent, respectively.

Fusarium wilt was found in a plantation of Taiwan acacia, an important fuel wood on the island. The disease, though still localized, appeared to be spreading rapidly in one area (PL-480).

6. Decay of Wood and Wood Products

Major accomplishments in this area are: elucidation of the role of nitrogen in the progress of wood decay; knowledge that the destruction of thiamine in wood can prevent fungal development; accumulation of data denoting the importance of tight decking in bridge construction and on-site preservative treatment and maintenance in reducing decay losses.

a. Decay of raw products. The thiamine that occurs naturally in wood is an essential requirement for fungal development. It may be destroyed by relatively simple methods involving a short soaking in solutions that raise the $_{p}H$, followed by heating as in kiln drying. Although such wood will probably absorb thiamine from its surroundings and become vulnerable to decay, the rate of absorption varies widely under different conditions of exposure. Treated panels exposed above ground in Mississippi were sound after 5 years whereas untreated controls were virtually destroyed by decay.

Pure-culture bioassays uncovered evidence that a number of common fungus inhabitants of soil can degrade certain wood preservatives. This suggests that, although these fungi have been considered relatively harmless to treated wood, they may indirectly cause damage by lowering the inhibitory level of preservatives to a point where the wood can be attacked by the usual wood-destroying fungi.

The practice of storing pulpwood of northern hardwoods in the form of chips is becoming increasingly common. However, fungal deterioration of stored chips is not well understood. A study of birch, beech, and maple chips in storage in the Northeast has been initiated. Biological aspects will include evaluation of specific gravity losses, characterization of discolorations, identification of causal microorganisms, and investigation of the physiology and individual destructive capacities of these organisms. A similar study of chip storage in the South was carried into its final phase.

Visual evidence of the microscopical changes effected by brown-rot and white-rot fungi in a hardwood and a softwood supplements previously obtained chemical evidence regarding the fundamental character and processes of decay. It was found that (1) decay of the cell wall does not depend on direct contact by the attacking fungus, but proceeds largely through enzymes acting within the cell at a distance from the fungus; (2) white-rot progresses through the cell wall layer by layer, whereas brown-rot occurs in more than one layer at a time; (3) the degree of lignification of the cell wall apparently is a large factor in resistance to brown-rot; and (4) unrecognized differences in the microstructure of the cell wall exist between hardwoods and softwoods.

Results from the first year of grant-supported research on the bio-chemistry of wood deterioration support the following general conclusions: (1) the nitrogen content of all species tested decreased progressively from the cambium to the sapwood-heartwood boundary or to the vicinity of the pith in species without typical heartwood, (2) the pith in all species was exceptionally high in nitrogen content, (3) the nitrogen content of 6 coniferous species was higher in rootwood than in stemwood, (4) summer wood contains less nitrogen than springwood of the same annual increments, and (5) a progressively increasing nitrogen content was associated in some tropical species with increasing parenchyma content.

In studies to determine the forms of nitrogen in wood, paper chromatographic analyses of water and ethanol extracts of both sapwood and heartwood of Pinus strobus and Populus grandidentata have shown that free amino acids are present in sapwood but not in heartwood. The free amino acids detected included aspartic acid, glutamic acid, serine, gycine, alanine, and arginine. These are all typical protein amino acids.

Continuing studies of the conditions that lead to growth and autolysis of the mycelium of a common wood decay fungus, Polyporus versicolor, have shown that autolysis in a synthetic medium is accompanied by: (1) depletion of the carbon source in the presence of large amounts of substrate nitrogen, and (2) higher pH values than in non-autolyzing cultures.

b. Decay of wood in use. On the basis of ammunition box studies (1959) several companies are marketing wax emulsion-sodium pentachlorophenate solutions for the temporary protection of lumber against wetting and stain during storage, shipment, and building construction. Tests with two such products showed that neither afforded worthwhile protection against stain or wetting at the commercially recommended 9 to 1 dilution but both were effective at a 5 to 1 dilution.

Wood is still the preferred material for utility poles, but the problem of suitably diagnosing a pole for interior decay continues to plague users. The Forest Products Laboratory cooperative study (Navy) to improve the situation was carried through the initial field phase. Seven species of fungi appear to be causing most of the pole decay throughout the United States. All of these are brown rotters, which materially improves the possibility of developing a visual test for pole decay. The interior

moisture content of most decayed poles was above the fiber saturation point, but many poles without decay were similarly wet. Site drainage seemingly had little influence on the incidence of decay in the regions covered, consequently it presumably could be ignored at least in inspections of southern pine poles in the East.

Typical wood bridges were examined in four Forest Service Regions to determine major decay factors and possible means of suppressing them. In all locations much of the decay in above-ground bridge members, such as piling tops, caps, stringers, and decking planks, results from leakage of rain or melted snow through the deck. A tight deck design accompanied by a sealing coat of asphalt or other comparable material should go far in alleviating the problem. The specific bridge members most seriously damaged by decay and the prevalent location of decay in these members indicated that on-site treating might provide a great deal of additional protection.

c. Decay of hardwood logging slash. When Nuttall oak tops were cut in the spring, stain and rot fungi enter and make 60 percent of the sapwood unusable. Sapwood of trees cut in October remain usable until the following April, by which time 35 percent of the volume was stained. Heartwood remains unstained about 2 months longer than sapwood. Rot makes sapwood unusable in 8 months after April cutting. Common blue stain fungi isolated were Ceratocystis, Diplodia, Basidiobotrys, Graphium, and Pullularia. The rot fungi most often cultured were Schizophyllum commune, Polyporus versicolor, Stereum complicatum, and Daedalea confragosa. Trees of all species studied except cottonwood disintegrate at similar rates. Five years after logging, twigs in the air had fallen and disintegrated, and small branches after 6 years. By 4 years after logging, small branches and twigs on the ground had been reduced by more than 50 percent. Cottonwood slash decomposed in about half these times. Cottonwood tops ceased being a serious fire hazard after 3 years while other hardwoods reached the low-hazard level in 6 years.

d. Natural durability of wood. In India, durable timbers were tested against some common wood-destroying fungi. Tests were completed with Teak, Bijasal, and Shisham against 6 fungi, and Toon against 2 fungi in addition to the normal test fungi (PL-480).

Thirteen commonly occurring decay fungi were screened for their efficacy as test organisms. Of these, Polyporus palustris, P. adustus, P. tulipiferae, Irpex flavus, and I. vallareus appear promising (PL-480).

Extractives, using organic solvents, have been obtained from teak heartwood. Decay tests with extracted wood blocks and blocks impregnated with these extractives are in progress (PL-480).

e. Causal fungi and their identification. Formal descriptions were completed and Cultural Identification Cards prepared for 24 forest fungi. For 16 more fungi, descriptions were amended to facilitate their separation from closely related or culturally similar fungi. Included are three commercial closely related species of Poria (P. eupora, P. luteoalba and P. rixosa) previously impossible to distinguish in culture.

Two new wood-staining fungi were isolated and described: Ceratocystis tremulo-aurea from aspen in Colorado and C. megalobrunnea from Nuttall oak in Mississippi.

Four isolates of Ceratocystis coerulescens were used to determine variations in carbon utilization on a liquid medium with ammonium chloride as the nitrogen source and 33 carbon compounds soluble or colloidal in water as the carbon source.

Twenty-three carbon sources were utilized by all 4 isolates, 8 carbon sources by single isolates, and 2 carbon sources by no isolates.

Work underway includes cultural and taxonomic studies of 5 species of Vararia, 6 species of Asterostroma and a detailed comparison of Fomes meliae, a brown rot of hardwood trees and logs, with the culturally similar Polyporus palustris, P. spraguei, Poria nigra and Daedalea quercina.

In 1964, 289 cultures including 36 species new to the Collections and 639 new haploid isolates representing 68 species were added to the Reference Culture Collections. Of these 68 species, 53 were new to the haploid collection. The total collections now number approximately 10,500 isolates representing about 700 species, including approximately 2,300 haploid isolates representing 180 species.

7. Miscellaneous Disease Studies.

The search for foreign diseases of possible economic importance to United States forests continues.

Surveys. A survey of epidemic forest diseases was carried out on Taiwan. One virus disease and 20 fungal diseases were identified among the specimens collected. A Nectria canker of mahogany (N. swieteniae-mahoganii) was identified as a new species. Formosan beauty-berry mosaic, Pestalotia blight of Chamaecyparis, and fortune paulownia scab were described in Taiwan for the first time (PL-480).

A study of diseases on Abies alba, A. pinsapo, Pinus halepensis, P. laricio, P. montana, P. pinaster, P. pinea, P. silvestris, and P. radiata in Spain has been completed. (PL-480).

In India, study of the metabolism of Loranthus parasitizing mango and guava trees revealed that polysaccharide phosphorylase activity was very low in homogenates of the mistletoe leaves. It was concluded that the leaves of the parasite contain an inhibitor of phosphorylase.

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IV. FOREST PRODUCTS AND ENGINEERING RESEARCH

A. FOREST PRODUCTS UTILIZATION RESEARCH

Problem

Forest products constitute a major asset in our present national economy and are one of the few renewable resources. Timber-based economic activities employed more than 3 million workers and accounted for approximately 6 percent of the gross national product in 1960 or about $25 billion. There is an urgent need, however, for research in forest products utilization to improve the present use of wood and to develop new uses for residual stands of low value timber or little used species which have developed on substantial acreage in small ownerships as a result of continued selective harvesting of the better timber. The development of uses for this presently unmarketable timber is essential to lend stability to the present industry, develop a basis for new industries, and to expand fully the potential of the acres involved.

The timber industry conducts a substantial amount of research. However, in general, the industry is a complex of small companies and lacks the unity of other basic industries such as aluminum, steel, plastics, and petroleum. In contrast to the timber industry, these competing industries are generally comprised of a few giant corporations which often singly employ a research staff larger than that of the entire timber-using industry.

The Federal Government has a strong interest and responsibility in forest products utilization research. There are very few forest products companies large enough to finance research programs, and the industry relies on the Federal Government for research assistance. Also the value of the Federally-owned timber marketed at over $150 million annually can be greatly enhanced by development of more profitable uses. As supplies of low quality timber increase, improved utilization must increase to keep the timber-based economy thriving.

USDA and Cooperative Programs

The Department has a continuing long-term program, involving both basic and applied research, to promote better utilization of the Nation's timber resource. Wood utilization research currently centers on increasing the serviceability of wood products, on developing new uses for wood, and on improving its quality. Included is research on the intrinsic wood quality of standing timber, log and tree grades, processes and treatments by which wood is made serviceable, pulp and paper, chemistry of wood, and wood engineering. Also two pioneering research units are located at the Forest Products Laboratory; one unit is studying the fundamental aspects of lignin chemistry and one is studying the use of analytical mechanics techniques for interpreting data.

A large part of the more basic and complex research is concentrated at the centralized Forest Products Laboratory. Paralleling this effort is the work at the regional Forest Experiment Stations dealing with the mammoth task involved in resolving regional and national wood utilization problems. In order that the various parts of the national program of Forest Products Utilization Research function properly in a coordinated program, new assignment of research roles has been made.

Assigned responsibilities for each of the 10 Experiment Stations and the Institute of Tropical Forestry are in coordination with the Forest Products Laboratory's research which emphasizes basic approaches. Each Station's responsibilities have been divided into two areas: (1) those constituting its major "mission" in the national program and giving its research scientists a specific direction and goal with respect to the national situation, and (2) those concerned with the regional situation and problems that can only be solved on the local or regional level.

To clarify the interrelationships of the various research units working on Forest Products Utilization Research the major or national assignments of each Station have been subdivided into three major classes: (1) Materials research, (2) Products research, and (3) Process research.

Under this classification system the major research assignments for the Experiment Stations are as follows:

Materials Research

Lake States - Primary Forest Materials
Northern - Alaskan Woods
Institute of Tropical Forestry - Utilization of Tropical Woods
Central States)
Northeastern)
Southeastern) - Log and Tree Grades
Pacific Northwest)
Pacific Southwest)

Product Research

Northeastern - Manufactured Hardwood Products
Rocky Mountain - Manufactured Softwood Products
Southeastern - Use of Wood in Housing
Pacific Northwest - Wood Construction Concepts

Process Research

Central States - Processing Hardwood Timber
Southern - Processing Southern Woods
Intermountain - Processing Western Woods
Pacific Southwest - Production Decision Systems

Assigned responsibilities for research that will lead to the better utilization of the regions' timber resources were also made to the Stations. The Stations will conduct research on the regional utilization situation, the qualities and characteristics of the commercially important woods of the region, and the conditions peculiar to the region that affect the utilization of wood. Cooperation will continue with each region's industry in solving specific problems, with Forest Products Laboratory national research program, with universities and industry research groups, and with other Forest Service activities, such as State and Private Forestry utilization and marketing functions.

A new program to get forest products utilization and marketing research results into use was initiated. In the past research information has been disseminated by the Forest Products Laboratory and Stations partly through training of

extension-type workers, clinics, demonstrations, and direct technical assistance to wood processors. This type of work will be gradually phased out of the forest products utilization and marketing research programs and will become the responsibility of the Cooperative Forest Management Division of State and Private Forestry. It is recognized, however, that the task of getting research results into use cannot be satisfactorily accomplished through the efforts of either Research or State and Private Forestry working alone. Therefore, a joint effort between Research and State and Private Forestry was established on a continuing basis to accomplish the job. Essentially the effort consists of Research (Forest Products and Engineering Research and Forest Economics and Marketing Research) assisting State and Private Forestry in developing and carrying out a technical assistance program for forest products industries. Dissemination of research results by the Stations and the Forest Products Laboratory will be limited largely to "wholesale efforts." The Station and Forest Products Laboratory will continue, however, to provide technical assistance in coordination with State and Private Forestry in situations where State and Private Forestry is not prepared to assume full responsibility.

The program also includes research involving techniques for improved utilization of the forest resources within the Appalachia Region. This research, aimed at resource improvement and increased economic and employment opportunities through broadened potential use of Appalachian timber species, is presently underway at the Forest Products Laboratory and both the Northeastern and Central States Forest Experiment Stations.

Cooperation with university and industry research is also employed in seeking solutions to both regional and national problems. During the past year cooperation has been with 24 colleges and universities, 25 Federal and state government agencies, 22 industry associations, 8 private laboratories or professional societies, and over 100 private companies.

Federal scientific effort devoted to research in this area now totals about 188 man-years plus 3.9 man-years in contract and grant research with non-Federal agencies.

A program of research is also carried on under Public Law 480 in Peru, Finland, Pakistan, and India. Currently eight projects are underway involving about 20 professional man-years per year.

Progress--USDA and Cooperative Programs

1. Wood Quality

a. Log and tree grade development. Research at the Pacific Northwest Station developed a three-grade system for inland Douglas-fir logs in standing trees. This system is easier to apply and accounts for more of the variation than the two systems for grading logs it replaces. It has been approved for Forest Service usage. Also tentative grading systems for inland Douglas-fir trees, hardwood veneer logs, and southern pine trees were completed and developmental work was initiated on other species.

Experiments at the Pacific Southwest Station showed that product grade output and value from logs could be predicted using mathematical expressions from multivariate multiple regressions. The development of electronic computer programs makes it possible to consider new ways of using quality information. In a parallel study a new technique permits predicting with greater accuracy the interdependence among

lumber grades produced from a log, as well as relationship between lumber grades and log surface characteristics.

The yield of alternative products (lumber and veneer) from old-growth, coast-type Douglas-fir was determined and the data made available to other public agencies selling stumpage. The data will contribute toward the development of improved tree grades for coast Douglas-fir. Also yield and value information from white fir logs in Oregon was published.

Research on lumber recovery on thousands of hardwood logs was used to provide information to buyers and sellers of timber for predicting lumber grade and value yield. For example, an investigation of Alaska birch showed that factory lumber yield of approximately 40 percent No. 1 Common and Better can be expected, and a Lake States Station study showed that pith flecks in sugar maple should be considered an important grading criterion. Further research resulted in the development of an interim hardwood veneer log grade specification for use by the Forest Service in appraising standing timber and a butt-log tree grading system for yellow poplar.

Northeastern Station exploratory studies on red pine indicate that the log grading system for inland Douglas-fir applies equally well to red pine in the Lake States. Another completed study provides a published standard procedure for recording log surface and log end characteristics for use in developing grading systems for all eastern softwood species.

b. Wood quality evaluation and genetic effects. Studies of wood density show that southern pines differ in specific gravity between species and by location. In the Southeastern states, density tends to increase from northwest to southeast with age providing the most significant variable. Other important variables include diameter, volume, local area, growth rate, rainfall, altitude, and longitude.

Wood density studies of loblolly and shortleaf pines in Arkansas show that the specific gravity of the merchantable portion of the tree can be estimated from breast high increment cores.

Wood density studies in the Southwest provide new specific gravity values for alligator, juniper, and Gambel oak.

c. Wood structure-wood property relations. Research on the effects of variations in fibril angles on basic strength showed that low stiffness and erratic shock resistance are associated with large fibril angles (30° to 50°). A study of slash pine shows that variations in fibril angle are closely correlated with tracheid length and cell wall thickness. Some gross anatomical features, like age and percentage of latewood, are less closely correlated with fibril angle. Variation in basic strength properties of wood are significantly affected by fibril angle alone or, when determined in conjunction with specific gravity, may account for 85 percent of the total variation in strength and stiffness. Both of these properties should be included in a critical evaluation of intrinsic wood quality.

d. Environmental, growth, and silvicultural effects. Research has shown that nearly all of the variation in specific gravity of Douglas-fir and redwood can be associated with variation in the number of tracheids per square millimeter and the average thickness of the tangential tracheid walls.

e. Sawmill improvement. An improved sawing method for southern pine significantly reduced the incidence and severity of warp in 2 by 4 studs. This method, in which saw lines are produced parallel to the bark, produced 43 percent more No. 1 Common and Better studs from butt logs. The average strength of the studs produced by the improved method was 10 percent greater than that produced by conventional sawing.

f. P.L. 480 - Peru. Under this study involving a collection of wood and herbarium materials from the trees of Peru, complete herbarium material from 103 trees has been acquired. Observations to date reveal eight species and one variety are new to botanical science.

2. Solid Wood Products

a. Machining and veneer cutting. Research shows that Douglas-fir and southern pine with similar growth rates will react much the same during processing into veneer and plywood. Slow growth for either species, that is, at least two annual rings per thickness of veneer, will reduce shelling, depth of knife checks, and veneer warp. Slow growth will also improve glue bonds and playwood panel appearance.

These and other research results provided the basis for analyses of the southern plywood industrial potential.

b. Product and process development. Thick particle boards, 1-1/2 inch and thicker and made with a center core of pulp-type chips, produce a stable, rigid board that appears suited for doors, tables, roof decking, desk tops, and partitions. The addition of high quality flakes to each face results in a dense surface that can be sanded and finished or can be overlaid with other materials. Such a board is low in density and can be made from poor quality raw materials. Sticklike particles in the 20-80 mesh size range, such as those obtained from hammer-milled flakes or planer shavings, produced molded parts superior in bending and dimensional stability but poorer in flow than cube-like particles that occur in sawdust from ripsawn material. In the search for more economic uses of residue material produced in planing lumber, a new approach to high-speed, high-volume planing yielded particle board flakes or pulp chips of high quality. The so-called "ringhead" planer, because it cuts across the grain, has great flexibility in the choice of particle geometry.

c. Wood drying. Yellow poplar lumber was dried at temperatures ranging from 121° to 232° C. to determine the drying rate and equilibrium moisture content for various drying conditions. Three-stage drying included a period of heat transfer to the wood, a period of heat transfer through the wood, and a period of equilibrium. Volumetric shrinkage was not affected by drying temperatures above 100° C.

Sawn southern pine veneers were dried in air, in a lumber kiln, in a jet dryer, in a conventional roller veneer dryer, and in a hot plate press with ventilated cauls. Temperatures in the last three treatments were as high as 300° F. Fastest drying occurred in the hot plate press and produced the least distortion. Resin exudation that might affect gluing occurred in some treatments. None of the treatments significantly affected veneer stiffness.

Research in air drying Central States hardwoods shows that volume losses of from 1 to 4 percent can be anticipated. Losses are the result of inadequate allowances for thickness and width in sawing.

Other studies provide guides for forced air drying tupelo gum furniture billets in solid stacks and for air drying Eucalyptus robusta lumber from Hawaii.

d. Glues and gluing processes. Techniques have been developed to make rapid evaluation of the durability of new adhesives. The effects of moisture, temperature, and cyclic shrinkage and swelling are correlated with long-term exposures.

Exposure studies showed that chemicals, such as fire retardants, present difficult gluing problems. When resorcinol resin adhesives and fire retardant treated wood are joined, an interaction of chemicals occurs causing premature jelling resulting in a poor bond. One study is searching for the causes of interference with the ultimate hope of overcoming this gluing problem.

The slight "give" in a glue joint in a load-carrying member actually increases the loading capacity of the structure. These joints are also able to absorb the swelling and shrinking stresses caused by moisture variations in wood members. A successful study was completed which demonstrated the principles.

e. Glued wood products. A rapid evaluation of glue joints in laminated timbers can be carried out within an 8-hour shift by employing vacuum and pressure for rapid impregnation of laminated wood specimens. Specimens are steamed and then dried with rapid circulation of air to induce severe drying stresses in the wood, resulting in tensile stresses on the glue line. This provides industry with a reliable method to test current work with a minimum of interruption to work schedules.

A 10-year exposure study of laminated red oak, Douglas-fir, and southern pine beams treated with 5 percent pentachlorophenol in No. 4 aromatic residual petroleum oil showed that this treatment provided excellent protection against checking. Similar beams treated with a waterborne preservative developed severe checking relatively early in the exposure.

Research has provided guides for manufacturing various glued wood products from low grade ponderosa pine lumber including vertically laminated beams, paper overlaid lumber, sheathing grade plywood, and particle boards. Other studies have shown the feasibility of manufacturing beams of maximum stiffness from southern pine boltwood. In such a system, small logs are squared without slabs or sawdust, thick veneer is sawn or sliced, laminae are sorted by stiffness classes, and glued up into beams of variable length and size.

f. Wood finishing. Microscopic studies of painted wood exposed to natural weathering revealed the development of microchecks in cell walls and between cells in summerwood. This provides a possible new explanation for the early flaking of paint from summerwood before failure over the springwood. The early failure of transparent coatings exposed to the weather was related to the diagonal checks that formed at bordered pits in springwood. The loss of wood substance from the surface exposed to ultraviolet light in the laboratory was observed in areas of presumable high lignin content. A similar degradation was observed in surfaces exposed to solar radiation but at a slower rate.

g. Fire performance of wood. Experiments on combustion rates of untreated and chemically treated wood showed that alpha-cellulose contributes most to the flaming and lignin to the glow. Several chemical compounds lowered the temperature of initial decomposition and increased the char.

Other studies show the effect of temperature, species, density, grain direction, and moisture content on the rate of char penetration for wood.

h. Preservative development and treating processes. A post mortem study of marine piling that had been destroyed by borers in harbors of wide geographical distribution sheds new light on the supposition that early failures are attributed to inadequate retentions of creosote. Even heavily treated piling may fail in as little as 4 years. When such cases occurred, the extracted oils were found to contain substantial quantities of saturated hydrocarbons, such as are abundant in petroleum oils and creosote distilled from vertical-retort tar. This applies to marine piling for southern and tropical waters exposed to borers and is the only situation in which the quality of creosote appears highly critical.

i. P.L. 480 - India. Progress is being made on the development of information regarding working qualities of Indian timbers. Experiments in planing techniques on several species have indicated that more satisfactory results are obtained with the lower as compared to the higher specific gravity species. It was also observed that smoother cutting resulted in higher power consumption indicating possible grain tearing in the rough operation as compared to actual cutting of the fibers in the case where the smooth surface was produced.

3. Wood Fiber Products

a. Pulping process investigations. A study of factors affecting yield increase and fiber quality in polysulfide pulping showed that the alkaline pulp yield from loblolly pine reaches a maximum with the addition of an increasing amount of polysulfide. With the use of 12 percent polysulfide sulfur, the yield of kraft pulp is increased from 50 to 61 percent, and the respective bleached yield of pulps from 44.5 to 53.5 percent. The strength properties of polysulfide pulps are comparable with kraft except tear which is slightly lower.

Polysulfide decomposes in alkaline cooking liquor before reaching the digestion temperature by an auto-oxidation-reduction reaction that has a very high temperature coefficient. This results in a large loss of polysulfide as well as active alkali. Therefore, the active alkali requirement increases with increasing polysulfide. The use of low digestion temperature, pre-impregnation, slow rate of heating to maximum temperature, and short or thin chips increases the efficiency of polysulfide. Further improvements in cooking conditions are expected to reduce the sulfur requirement to more practical levels.

Although the rate of delignification in pulping with polysulfide is considerably faster than in kraft, the increase in pulp yield was primarily due to protection of wood carbohydrates, probably through the oxidation of their reducing end groups by polysulfide and decreased peeling-off degradation in alkali. The yield of glucomannan was doubled, accounting for one-half of the pulp yield increase, and 10 percent increases in cellulose and xylan were responsible for the other half. The response of loblolly pine, white spruce, balsam fir, and Douglas-fir to polysulfide pulping was similar. With the red oak, the maximum yield increase was about one-half that of pine, mainly because of improved xylan retention.

b. Pulp properties. In the concluding work on the swelling of cellulose fibers, a relation was demonstrated between cell wall structure and the practical quality of prehydrolysis-kraft viscose rayon pulps. The study showed that when the caustic soda extraction treatment used in the production of these pulps is optimum, they react uniformly and completely in the viscose-making process. Microscopical

observation of the swelling of these fibers in a standard cellulose solvent reveals that the anatomical layers of the cell wall go into solution at the same rate. When, however, extraction conditions are not optimum, the innermost layer is seen to be resistant to the swelling agent.

Further research has developed a simple method for measuring relative bonded area of surfaces of the fibers in paper involving the electrical conductivity of a paper. The method shows considerable practical promise for basic studies of the strength and optical properties of paper.

c. Fiber processing. Research on chemical processing treatments for improving the quality of pulps showed that spruce and hemlock sodium bisulphite pulps can be bleached successfully in two stages with 6 percent of available chlorine as calcium hypochlorite in the first stage and 1 percent of sodium hydrosulphite in the second stage. Yield of bleached pulp was found to be 97 percent exclusive of any mechanical loss of fiber as compared to about 93 percent with a chlorination stage and the same brightness. Strength of bleached pulp was found to be adequate.

d. Papermaking processes. A major breakthrough has been made in the manufacture of the base paper for tabulating and computer cards. A much higher level of dimensional stability, previously unobtainable on the paper machine, has resulted from a method developed for restraining paper while it is being dried continuously. This was accomplished with a combination of one expander roll and two high-temperature felted dryers at specific locations in the paper machine dryer section.

e. Converted paper products. Commercial production of corrugated boxes with high stiffness after exposure to high humidity and water became an accomplished fact. A large papermill manufactured linerboard and corrugated medium treated with a water-soluble phenolic resin and successfully converted these treated boards into corrugated boxes.

4. Wood Chemistry

a. Lignin structure and utilization. In the Pioneering Unit in Lignin Chemistry, completed research on the products of enzymatic coupling of simple phenolic models has confirmed the idea that biphenyl and diphenyl ether linkages exist in lignin and has given evidence of routes by which monomeric phenols may be incorporated into the final polymer.

Since paper chromatographic methods for analyzing the mixture of phenols expected from degradation of lignin in black liquors could not be carried out quantitatively, a more efficient gas chromatographic method was investigated. This method was shown to provide excellent separation of eight known compounds.

b. Chemistry of wood and bark extractives. Research on the benzene extractives of pine barks had previously yielded a new triterpene pinusenediol. This has now been found to be identical with serratenediol, an unusually interesting new triterpene recently reported by Japanese scientists in a club moss. Pinusenediol is unique among known triterpenes in that it has a seven-membered ring in its structure. Solving this puzzle opens a way to the identification of already isolated new complex terpenoids and other substances in wood and bark.

Further research on a procedure for the analysis of tall oil and pine extractives has resulted in the separation of a mixture of nine commonly occurring resin acids

by thin layer chromatography. Additional research has centered on developing methodology for a direct quantitative analysis of mixtures of resin and fatty acids by gas chromatography.

The study of polyphenols in wood has resulted in the isolation in crystalline form of an unusual glycoflavonoid from the wood of Vitex lucens. This is the first compound ever described that has two sugar residues attached through carbon atoms to the flavonoid group.

c. Surface and polymer chemistry of wood. Continued research on surface treatments to improve performance of wood finishes demonstrated that surface stabilization has a dramatic effect on the weatherability of uncoated ponderosa pine and redwood when compared to wood surfaces not stabilized. Checking and defiberization are markedly reduced. Further research showed that the weathering of a clear finish on phenolic resin surface-stabilized ponderosa pine heartwood is improved, but it remains a problem on surface-stabilized sapwood. Other studies showed that a rapid, simple resin surface treatment that depends on capillarity or wicking alone can be effective.

Experiments on changes in surface film brought about by weathering showed that polyurethane finish was a strong absorber of ultraviolet light and the finish was thereby markedly changed. While it retained its excellent ability to exclude moisture, it lost its elasticity and was less able to resist the damage caused by mild swelling stresses. This fact appears to explain the good performance of the finish over stabilized heartwood and its poor performance over stabilized sapwood. In the latter case, moisture from the rear of the panel caused swelling that damaged the finish.

Other research showed that wood stabilized with polyethylene glycol-1000 suffers from a high hygroscopicity and a rather unpleasant "feel" at high humidities. An investigation of the higher glycols showed them to have lower hygroscopicity, and X-ray diffraction studies showed this was due to a marked crystallinity of the products. Wood treated with polyethylene glycol-4000 shows little of the disadvantage shown by wood stabilized with polyethylene glycol-1000. It has a better feel and can be finished and glued more readily.

A study of the effects of wood extractives on the setting of portland cement showed that inhibition of portland cement to set by finely ground wood can be measured quantitatively by determining the time required for the mixture to attain a maximum temperature in a Dewar flask. The method can distinguish between inhibitory and non-inhibitory batches of single wood species. Calibration for the effect of wood particle size, Dewar heat loss, and system heat capacity is necessary. Decayed wood, heartwood, or spring cut wood may greatly increase the normal setting time of a cement and wood mixture. This work will be highly significant to manufacturers of building boards of portland cement and excelsior who have found that portland cement used in contact with southern pine excelsior sometimes fails to set.

d. Analytical development, instrumentation, and service. In the continuing search for improved analytical techniques, a thin layer chromatographic method was developed which provides great versatility and an enormous saving in the time required to obtain accurate results in chemical analysis.

The method for chromatographic analysis of chemically refined cellulose developed at the Laboratory is now the ASTM standard method.

e. P.L. 480 - Finland. Studies at the University of Helsinki on the aerobic bacterial degradation of lignin has established the characterization and identification of bacteria which is able to grow on lignin as the sole carbon source. Bacteria had not been previously thought to play any part in lignin utilization in nature. Further determinations have disclosed that some lignin transformation can take place non-enzymatically as a result of chemical reaction between bacterial cell components and lignin. Part of the soluble lignin is absorbed tenaciously by the bacteria cell wall and cannot be brought back into solution.

Research at the State Institute for Technical Research, Helsinki, has developed important concepts in cellulose chemistry and contributed considerably to understanding of basic cellulose structure through use of new radiation detecting equipment for cellulose crystallinity measurements. Development and use of a new cellulose solvent for obtaining molecular weight data by light scattering and viscocity measurements are also contributions of considerable merit to wood chemistry research.

5. Wood Engineering

a. Fundamental wood properties. Research designed to insure greater reliability in using Western Woods Density Survey data on specific gravity distribution and known mechanical property-specific gravity relationships resulted in improved estimates of average structural properties for nine western species, along with estimates of the standard deviations and development of a method that makes possible the combination of several species or species subdivisions into a single group for marketing purposes.

Reevaluation of western hemlock showed that the strength and related properties are essentially the same as was found many years ago. Thus no important changes are made in average properties by pooling the data from all trees. Wood of the Hawaiian-grown Eucalyptus saligna, a plantation-grown species suspected to have structural potential, was found to have properties similar to those for shagbark hickory, except that it is lower in specific gravity and toughness.

b. Properties of wood-base and related materials. Research on earthquake resistance of standard wood-framed wall panels sheathed on both faces with hardboards showed that distortion (racking) produced by a severe earthquake (the El Centro one of 1940) would be 0.17 inch, whereas deformations of at least 0.40 inch were required to produce any appreciable permanent distortion. It was concluded that sheathing of hardboard, properly applied to one face of a wall construction, would provide adequate resistance to earthquake forces. This is also a significant finding for those earthquake areas of the world where home construction methods are predominantly mass masonry and loss of life from earthquake is large.

c. Design criteria. Failure of flat roofs due to ponding of water indicated an urgent need for proper design information for this type of roof. Glued laminated wood beams with decking are frequently used for such roofs. Research on the effect of ponded water led to the development of design criteria to show that ponding can cause progressively increasing deflection and eventual collapse unless proper beam and deck stiffness are determined and used. The design criteria permit selection of deck and beam stiffnesses to prevent progressive increase of deflection under ponding as well as to enable computation of deflection and stresses induced by ponding.

Techniques were developed to permit bonding of a stressed, high-strength steel plate to the bottom of a glued laminated beam, wherein the prestress is developed through

the adhesive that bonds the steel to the wood. This research showed a similar increase in bending strength and a decrease in variability for beams with the steel plate on the tension side as was found for beams prestressed with a steel cable.

Failure of some laminated structural members in use led to further research on design methods for tapered wood members. This research developed special design criteria which include considerations of both stress and deflection for straight tapered wood beams of single and double taper. The study showed that the combined action of bending stress, shear stress, and vertical stress must be considered in designing beams because these stresses can all be maximum at the same point in the beam. Previous designs ignored changes in stress distribution due to taper of section.

Effective utilization of structural lumber on the tension side of glued laminated beams or as tension elements in trusses requires a knowledge of the tensile strength of the material. The strength is affected by knots and grain deviation and is probably a composite of tension parallel-to-grain, tension perpendicular-to-grain, and shear strength. This strength value has been impossible to measure in structural elements by conventional means because of difficulty in gripping the ends without inducing severe localized stresses. A special tapered grip was developed which makes it possible to test members up to 2 by 6 inches in cross-section size. Studies to date have shown that growth characteristics have more deleterious effect on the tensile strength of structural members than was generally recognized.

Research on various contemporary fasteners for shipping container applications showed that the dynamic and static withdrawal resistance of nylon-coated staples and helically threaded nails was not reduced after 360 days of storage after driving. In contrast, bright nails lost considerable withdrawal resistance during this period. Thus, containers made with the nylon-coated or helically threaded fasteners would be expected to perform better than conventionally fastened containers after storage. Other research on the performance of bolted joints showed lower performance in dry fire retardant treated wood than in dry untreated wood. Also, a study showed that withdrawal resistance of nails in treated material increased during exposure to high humidity.

d. Structural utilization. Further investigations in construction of earthquake resistant houses showed that in the Anchorage, Alaska, earthquake, light wood frame buildings with walls that were well fabricated to act as diaphragms withstood the earthquake shocks and showed surprising resistance to ground subsidence and displacements. The importance of proper fastening to insure performance of the structure as a unit was clearly illustrated. Wood construction in general performed in an excellent manner as indicated by a study of the area a few days after the earthquake.

Stressed skin panels suitable for use in trusses were developed 25 years ago by research. The continuous and systematic observation of the experimental units showed that, with the passing of time, these prefabricated structures performed in a satisfactory manner. The records of these old structures become increasingly important to give confidence in the permanence of such new type constructions, particularly where adhesives are used. Recent experiments included the destructive loading of a two-story stressed-skin panel house after nearly 27 years of service. Static and impact loads applied to floor panels and horizontal load applied to the entire house showed that the structure had good strength properties after this period of exposure.

Research on the effects of strength and rigidity of new kinds of nailed truss joints subjected to moisture cycling or long time nominal loading showed small losses of strength but greater losses of rigidity.

Studies of wheel load distribution on decks of timber highway bridges showed that the conventional laminated deck on timber stringers distributed the load more uniformly than had been recognized before and thus permitted more liberal design recommendations. These findings were recommended for immediate use at a meeting of the Western Association of State Highway Officials. Studies in Alaska revealed that bridges made of closely packed round logs tied by cables and covered with gravel showed appreciable wheel load distribution and promised increased design economy.

Further research on the more efficient use of dimension lumber in light framing was directed to the application of nondestructive test methods, such as machine grading. The machine grading system developed by industry is a highly important step toward more efficient use of lumber and the Forest Products Laboratory has maintained its position as technical advisor to the lumber industry and to the American Lumber Standards Committee. Research included a cooperative study with the Federal Housing Administration (FHA) where 300 machine-graded 2 by 4's of western woods for trussed rafter fabrication were graded by conventional visual means and tested for strength and stiffness in bending, compression, or tension. The results of this research took into consideration three evaluations of each piece; from the machine grader, from visual stress grading, and from the laboratory testing machine. The results showed that the day-to-day performance of the machines was not as good as when first installed.

e. Packaging. A study of corrugated fiber containers under normal handling and storage conditions showed that they perform satisfactorily in carrying loads in accordance with the requirement of Rule 41 of the Consolidated Freight Classification. Under adverse conditions of high humidity and moisture, however, their compressive strength may be reduced by as much as 90 percent of their dry strength.

f. P.L. 480 - Finland. Research at the State Institute for Technical Research corroborates compression strength and modulus of elasticity values recently determined for northern red oak by the Forest Products Laboratory. Nearly 6,000 tensile tests and more than 3,000 compression tests have been completed on various species.

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B. FOREST ENGINEERING RESEARCH

Problem

Forestry operations in the United States, and in the world in general, have not kept pace with other basic industries in improving labor output, in mechanization and automation for improved efficiency, and in reducing the physical drudgery involved. Man-strength hand operations still retard realization of an industrial revolution in most wood operations. Mechanization comparable to that achieved in American agriculture is sorely needed.

The forest industries are, historically, decentralized. There are many woodland owners, contract loggers, mill operators, equipment manufacturers, and sales organizations, each concerned with their individual problems. Equipment manufacturers, generally, have done a remarkable job in producing the machinery used in today's operations considering that they have been able to attack only subelements of overall systems without adequate engineering guidance from the purchaser. Neither the purchaser nor the manufacturer has been staffed to analyze the whole problem and specify operational goals.

Not only have the forest industries lagged in mechanization and improved efficiency, they are now beset by increasing restrictions due to competing forest interests, such as recreation, water, wildlife, and livestock uses which tend to increase the already high costs.

The constant price squeeze on wood products in the marketplace requires more efficient bulk collection methods for harvesting and delivery of raw material to processing plants. New systems of logging are needed for harvesting of lower valued timber, for operations in more difficult access areas, and for operations in areas with multiple use constraints.

Accordingly, research is urgently needed to establish the operational criteria for forestry operations and to develop the concepts required to perform them economically and in accordance with good land usage.

USDA & Cooperative Programs

Five problem areas in United States forestry have been selected for research attack. These problem areas characterize engineering obstacles to, or opportunities for, achievement of forestry and land management objectives in large segments of United States forestry. These areas can best be described as complexes having special problems or opportunities created by interrelated factors such as timber values, markets, accessibility, silvicultural requirements, watershed and recreation needs, current or potential industrialization, degree of mechanization, terrain, and weather. The areas have been selected on the basis of combinations of factors which create a problem or situation.

A research program has been established for each forestry problem complex in the geographical area of the country where the problem is dominant. These programs are located on or close to college or university campuses and operate in close cooperation with the engineering schools and with other disciplines in the institution. The program is designed to improve the efficiency and performance of forestry operations through the application of systems engineering techniques.

The following problem areas or complexes have been selected:

1. Steep, erosible mountain slopes with small stemmed timber of relatively low value.--The problem is characteristic in the lodgepole pine forests of the Rocky Mountain region of the United States but similar conditions exist elsewhere, particularly in the western United States. The research program is located at Bozeman, Montana and operates in cooperation with Montana State College.

2. Intensive forest management complex.--The problem is characteristic of forests in the South and involves mechanization of the "timber factory" production from "pollen to product," reduction of excessive hand labor in current methods to meet requirements of an ever-diminishing labor supply for forest work. The research program is located at Auburn, Alabama and operates in cooperation with Auburn University.

3. Deteriorated northern hardwood stands.--The problem is characteristic in the hardwood forests of the Great Lakes area, but similar conditions exist in the Northeast and to a limited extent in the South and Southeast, and involves the removal of current low value stands without economic loss and preferably at a profit, preparation of site for replanting to improved species, and planting of new stock. The research program is located at Houghton, Michigan, and operates in cooperation with Michigan Technological University.

4. Virgin timber types with heavy logging debris, difficult access, high road construction costs.--The problem is characteristic of the forests of the Pacific Northwest and Alaska, but similar conditions may be found in California, and inland areas of the West. The research program is located at Seattle, Washington, and operates in cooperation with the University of Washington.

5. Large volumes of low value hardwoods on steep slopes, low densities per acre and interspersed with some high value hardwoods, most stands in small ownership patterns.--The problem is found typically in the Appalachian area of the eastern United States. The research program is located at Morgantown, West Virginia, and operates in cooperation with the University of West Virginia.

Close liaison is maintained with other domestic and foreign agencies engaged in forestry equipment research and development, and with equipment manufacturing industries and defense laboratories.

The program is directed particularly to original applications designed to revolutionize forest production, protection, and utilization operations while considering other multiple use requirements.

The Federal scientific effort devoted to research in this area totals 15 man-years intramural and 5.9 man-years extramural.

Progress--USDA and Cooperative Programs

The engineering research program of the Forest Service represents a new approach to improving the efficiency and performance of forestry operations wherein entire systems are analyzed to identify technical problem areas, criteria, parameters, and best opportunities for payoff on research investments and efforts. Early work has concentrated on studies contributing to basic understanding and knowledge of critical elements of forestry materials handling operations. A few of interest are:

1. Pipeline Transportation

A subscale pipeline has been constructed and tests are underway to determine the basic engineering criteria needed for large pipeline design and evaluation. In a conceptional application of the mathematical model to a proposed pulpwood sale area in Alaska, a potential saving of 58 percent over the cost of conventional hauling methods was indicated. Even though all engineering cost factors cannot yet be evaluated precisely, savings of this magnitude indicate the attractiveness of investigating further the basic flow phenomena and technology of pipeline systems.

2. Logging Road Cost Reduction

Study results indicate that full scale use of the large single tread tires in place of dual tires could justify a saving of 15 to 20 percent in the amount of ballast or base course material needed for road construction. In Region 6 these savings could range between $750 and $1,000 per mile. If applied to only 50 percent of the 2,000 miles of ballasted road built per year in that Region alone, the saving would be between $750,000 and $1,000,000 per year. The research study has been completed and plans are underway to operationally evaluate the results.

3. Balloon Logging

The second phase of a systems analysis on the concept of balloon logging has developed the operational and support requirements and the economic limitations of such systems. Theoretical results of this logistics study (Phase II) and the previous analytical study (Phase I) indicate that balloon logging may be both economically and technically feasible under proper conditions. Plans have been completed for a full scale operational test and evaluation program scheduled to begin in the fall of 1965. This will be a cooperative effort with a logging operator, Goodyear Aerospace Corporation, engineering research, and Willamette National Forest personnel participating.

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V. FOREST ECONOMICS AND MARKETING RESEARCH

A. FOREST SURVEY

Problem

Up-to-date information on the Nation's forest resources and sound technical interpretations of the present and prospective timber supply and demand situation are essential to sound policy and program decisions on national, State and local levels. The nationwide Forest Survey provides the only comprehensive data on these forest resources, including the area and condition of forest lands, the volume and quality of standing timber currently available, the ownership of forest land and timber, trends in timber growth and mortality, and present and prospective amounts and kinds of timber cut for industrial use. With the rapid changes that occur in timber resources as a result of growth, cutting and land use changes, there are increasing needs for periodic inventories and analyses of the timber situation for all forested areas throughout the Nation.

USDA and Cooperative Programs

This continuing long-range program of applied research is conducted primarily through the Regional Forest Experiment Stations of the Forest Service in cooperation with State forestry agencies, wood-using industries and other contributors of manpower and funds. All the 759 million acres of forest land in the United States has been inventoried at least once, and much of the 509 million acres of commercial forest land has been re-inventoried at least once. Resurveys are being made at intervals of 8 to 15 years in different States. Comprehensive national studies of the forest situation and outlook are made on an 8 to 10 year schedule.

Research on timber resource surveys and appraisals involves about 82 professional man-years annually.

Progress--USDA and Cooperative Programs

1. Field inventories

The nationwide Forest Survey has been completing inventories in the various States on a cycle averaging slightly over 10 years. During the past year field surveys were conducted primarily in Alaska, California, Kansas, Kentucky, Louisiana, Michigan, North Carolina, Oregon, Pennsylvania, South Dakota, Texas, Virginia, and Washington.

2. New national appraisal of timber supply and demand completed--"Timber Trends in the United States"

Results of this new appraisal indicate that prospective timber growth and inventories in the United States with recent levels of forest management will be sufficient to meet projected demands for the next two or three decades, but not in the later years of this century. Timber supply-demand relationships in the United States have generally improved significantly over the past decade or two as a result of fire control and other forestry programs. Growth of softwood

sawtimber in 1962 was approximately equal to the cut, while growth of hardwood sawtimber was about 60 percent greater than the cut. Declining quality of timber resources represents a major problem for wood-using industries, and continuing declines in tree size and quality are to be expected if forest management efforts are only maintained at recent levels.

The timber supply outlook is relatively favorable for the pulp and paper industry, partly because of the impressive increase in use of species and materials formerly considered unusable, the more favorable outlook for total inventory of fiber, and major improvements in technology. For the lumber and plywood industries the outlook is not so encouraging. For these industries, the downward trends in timber quality and size point to rising costs of production and serious marketing problems, unless technological improvements can be accelerated. Imports of timber products are likely to increase somewhat, but most of the projected timber supply required to meet future U.S. demands is expected to come from forests of this Nation.

Domestic timber supplies could be increased sufficiently to meet projected timber demands in the year 2000 through more intensive forest management, such as timber stand improvement, increased planting and protection, and closer utilization of timber in the woods and in manufacturing plants. Farm and miscellaneous private forest land ownerships are of key importance in achieving such improvements in management of forest lands since these ownerships comprise about 60 percent of all commercial forest lands in the U.S.

3. West Virginia's forest resources increasing

A recent resurvey of West Virginia showed many significant changes since the initial survey in 1946-49. The area of commercial forest land increased 15 percent in this period, largely as a result of abandonment of 1-1/2 million acres of farm land. Almost three-fourths of West Virginia's land area is now in forests. Annual growth of sawtimber has averaged somewhat more than double the cut of nearly one-half billion board feet. Growing stock volume has risen almost 5 billion cubic feet between inventories--almost an 80 percent increase. Saw logs for lumber is the leading timber product, with pulpwood amounting to about one-third as much as the lumber output.

4. First comprehensive survey of Colorado completed

The first complete inventory of Colorado's forest revealed a volume of 52.7 billion board feet of sawtimber on 12.3 million acres of commercial forest land. Sawtimber stands occupy slightly more than half of the commercial forest area and younger stands the remainder. Almost nine-tenths of the primary timber products now being harvested is accounted for by lumber. Forest values from water, recreation and grazing must be considered as of major importance along with timber in the management of Colorado's forests.

5. Pulpwood production in the South continues to increase

Pulpwood production in the South reached 26.6 million cords in 1963, a 4 percent increase over 1962. The South produced 60 percent of the Nation's total pulpwood. Georgia was the leading pulpwood producing State with 5.5 million cords, or over one and a half times as much as the next State, Alabama. Pine roundwood comprised 64 percent of the total production of pulpwood in 1963, compared with 87 percent in 1953.

6. Midsouth produces 30 percent of the United States hardwood veneer logs

Production of hardwood veneer logs in the Midsouth in 1963 totaled 249 million board feet. Alabama was the leading producer with 29 percent of the total output. The industry showed a marked preference for soft-textured species; sweetgum alone made up 36 percent of the total log output in 1963. Production of softwood veneer logs was barely 6 million board feet in 1963 but a southern pine plywood industry is developing and the growth potential of this industry points to huge gains in the future production of pine veneer logs.

7. Lake States pulpwood cut continues to climb

The harvest of pulpwood in the Lake States has been increasing at an average annual rate of about 10 percent. About 96 percent of the pulpwood produced in 1963 was roundwood and the remaining 4 percent wood chips, slabs and veneer cores.

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B. FOREST ECONOMICS

Problem

Efficient investment of funds for production of timber, forest recreation, and other forest goods and services involves increasingly complex decisions in choosing among resource development alternatives. The magnitude of this problem is suggested by the fact that current expenditures for the development, protection and production of forest resources on the 770 million acres of forest land in the United States now exceed $400 million annually and are steadily increasing.

Administrators of public forests require improved criteria and guides to efficiently allocate public funds among different forest practices, production units and resource development opportunities. Of special importance is the development of procedures for integrating and balancing multiple uses of forest land for greatest public benefit in meeting rapidly expanding public demands for timber, water, wildlife, recreation and other services. Managers of industrial forests and the 4-1/2 million farmers, businessmen, professional people and other owners of private forest land also require improved information on costs and returns of forest management and use as a basis for making production and investment decisions in the management and development of their forest lands.

USDA and Cooperative Programs

The Department conducts a continuing long-term program of applied forest economics research mainly through the Regional Forest Experiment Stations of the Forest Service. Forest economics research is closely coordinated with timber management research in studying problems of timber growing; with forest fire, disease, and

insect research in appraising problems of forest protection; and with watershed, range and recreation research in evaluation of competing and multiple uses of forest lands. Cooperation is also maintained with the Economic Research Service, State Agricultural Experiment Stations and Forestry Schools.

Forest Service effort devoted to research in this field totals 27 professional man-years annually.

Progress--USDA and Cooperative Programs

1. Economic factors influence management of private nonindustrial forest lands

An evaluation of the findings and conclusions in research publications dealing with the characteristics and objectives of private nonindustrial forest landowners in the United States emphasizes that forestry must be viewed as an investment enterprise with heavy capital requirements relative to earning potentials. The intensity of forestry practiced on private nonindustrial forests is closely related to the ability of owners to accumulate capital assets in the form of forest land, growing stock and improvements. Rates of return from forest assets relative to alternative investments are identified as a principal economic determinant of private forestry practices. Other economic considerations influencing owners' decisions include requirements for current income, liquidity preference, high costs associated with small-scale enterprises, and nonmonetary objectives of many forest owners.

2. Computer systems provide guides for better forest planning

Computer programs are being developed to simulate forest management operations, including determination of the influence on management costs and incomes of a large number of alternatives relating to such factors as rates of timber harvest, price assumptions, property and severance taxes, costs of borrowed funds, and mortality rates. A related computer system is now available which can efficiently compile map data on multiple uses and management. This system transforms conventional map data into numbers which are punched into cards. A computer then assembles and displays information required for each land management planning task. The computer program can select information from several maps, prepare tabulations, and combine map data with related information on treatment costs, yields and benefits.

3. Economic model indicate optimum stocking levels and rotations

A model has been developed for simultaneously determining optimum stocking levels and rotation ages for pulpwood and sawtimber management in timber stands with varying stumpage prices, stand ages, site qualities, stocking levels, guiding rates of return, and regeneration cost levels. Application of the model in planning the management of loblolly pine showed that stocking levels based on dollar returns are much lower than levels which produce the greatest wood volume per acre. Rotations should be longer on good sites than on poor sites, especially if a premium is paid for higher quality sawtimber. In general, optimum stocking levels were more sensitive to economic variables than rotation age.

4. Some management practices profitable on farm forests in Virginia

An investigation of 105 farm forests in the southern Virginia Piedmont showed that in pine forests interplanting poorly stocked seedling and sapling stands was the

only cultural treatment that would increase earnings sufficiently to provide a profitable return on investments. Thinning and release of hardwood poletimber and sawtimber stands were also found to produce investment returns of approximately 5 percent.

5. Thinnings profitable in second-growth Douglas-fir timber

Thirteen years of commercial thinning in Douglas-fir stands on the McCleary Experimental Forest in Washington have provided annual cash incomes and have increased the earning rate of the remaining growing stock. Frequent light thinnings were found financially superior to no thinnings in stands younger than age 55. Older stands approaching 70 years were estimated to be financially mature and ready for final harvest and regeneration assuming continuance of current stumpage price levels. If stumpage prices for second-growth Douglas-fir should increase 50 percent in the next 20 years, however, then continued light thinning of these older stands would be financially superior to immediate harvesting.

6. Site quality a major influence on forest earnings in the Lake States

Analysis of timber management alternatives for red pine plantations in the Lake States shows that site quality influences forestry earnings substantially more than initial spacing, density after thinning, or rotation age. Earnings on forest investments on low sites were estimated at 20 percent in contrast to more than 5-1/2 percent on high sites.

7. Low infection rates may mean high costs for blister-rust control

Data obtained from a study of white pine management alternatives in the Northeast show that serious infections of white pine blister rust now occur only occasionally over much of the white pine range. Costs of locating and treating white pine stands in low-hazard areas represent an increasingly important factor in appraising the economics of control programs.

8. Forest ownership influences timber management in Michigan

State and National Forest lands in Michigan are contributing an increasing proportion of the timber cut annually. Better forest management, larger scale operations and more effective marketing are the main factors influencing this trend. The declining share of the annual timber harvest from private ownerships is attributed to expanding urbanization, forest land fragmentation, absentee ownership, owner disinterest in timber sales and generally less intensive forest management.

9. Watershed treatments chiefly affect forage production

Studies conducted as part of a comprehensive program of economic evaluation of land treatment measures in Arizona show that converting alligator and Utah juniper stands to grass increases forage production but has little effect in improving water yields. Herbage production on treated and untreated watersheds was measured as follows:

	Treated watershed	Untreated watershed
	(Pounds per acre)	(Pounds per acre)
Perennial grasses....	144	61
Forbs and half shrubs	1,074	75
Shrubs.....	6	18

10. The timber owner and his Federal income tax

A new handbook on Federal income taxes presents in nontechnical language information needed by individual timber owners in handling Federal income tax aspects of their forest operations. The handbook tells how to treat the costs of forest ownership and operation, for example, receipts from sales of timber and other forest operations, and physical losses of timber from casualties, thefts and condemnations. Also included are questions and answers, problems, timber provisions of the Internal Revenue Code and Regulations and Selected Revenue Rulings.

11. National Forest contributions to State and local governments, 1962

A sampling study of selected National Forests shows that amounts that might be payable on National Forest lands and timber if payments were equivalent to taxes on similar property in private ownership would have averaged about 43 cents per acre in 1962. Actual payments of 25 percent of receipts averaged 19 cents per acre. Other "payments in-kind" for fire control, road construction and other measures that States or counties would need to incur in the absence of Federal outlays amounted to an additional 44 cents per acre.

12. Forest industry capacity, production and log supplies in the Douglas-fir region

Expansion of the plywood industry in the Douglas-fir region between 1951 and 1960 came largely at the expense of lumber industry log supplies. Lumber industry capacity decreased by 2 billion board feet log scale in this period, but this was more than offset by an increase of 2.3 billion feet in plywood capacity. Total log production for lumber and plywood remained relatively stable at 10.9 billion feet during this period, while log consumption for pulp likewise remained fairly constant. The prospective log harvest in the Douglas-fir region for the 1960's was estimated at 12.1 billion board feet, log scale, almost a billion feet less than the installed sawmill, plywood and pulp capacity in 1960. The outlook is thus for further declines in lumber capacity, particularly in western Oregon where unused capacity is heavily concentrated.

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C. FOREST PRODUCTS MARKETING

Problem

The increasing availability of timber supplies represents an opportunity for much-needed industrial development and increased employment in many rural areas of the Nation. Realizing the potential contributions of timber resources to the Nation's economy, however, will require expanded markets for wood products, industrial adaptation to available wood supplies, and more efficient processing and sale of wood products. Appraisal of opportunities for expanding wood markets will involve the evaluation of varied factors that influence the amount and kind of wood products and other materials used in construction, manufacturing, shipping, and other markets, as well as studies to determine opportunities whereby the competitive position of wood products may be strengthened through improved processing and marketing systems.

USDA and Cooperative Programs

This is a continuing program of applied research conducted in part by Regional Forest Experiment Stations and in part by the Washington staff of the Forest Service. Close cooperation is maintained with other scientists engaged in forest products marketing research and in related economics, utilization and engineering research within public agencies and timber products industries. Cooperation also is maintained with the Statistical Reporting Service, State Agricultural Experiment Stations, forestry schools, Bureau of the Census, Federal Housing Administration, National Association of Home Builders, and other organizations that do research or otherwise have access to data pertinent to analyses of current and prospective markets for wood and other materials. Forest owners, loggers, other producers, and various users of wood products also cooperate by supplying production, processing and sales data.

Federal effort in this area of research totals 49 professional man-years annually.

Progress--USDA and Cooperative Programs

1. Prospective future demands for timber products analyzed

A recently completed comprehensive national analysis of trends in consumption of timber products in construction, manufacturing, shipping and other end uses indicates that the Nation's demands for timber products by the year 2000 may exceed current use by 80 percent. During the past four decades total use of "industrial" wood in the United States (i.e., all wood products except fuelwood) increased by about one-third, reaching 10.7 billion cubic feet in 1962. Projections of future wood demands developed in this study rise to a total of 20.8 billion cubic feet by 2000. Lumber use is projected to increase from 37.3 billion board feet in 1962 to 53.5 billion board feet in 2000, with nearly 90 percent of the increase in construction markets. Projections of plywood consumption show a prospective increase of 2.7 times, with approximately 70 percent of the increased use in construction. Demand for woodpulp is projected to increase nearly 3-fold by the end of the century.

These projected demands for wood products represent about 21 percent of the projected use of industrial raw materials by the year 2000, roughly in line with recent trends. Maintaining this sizable proportion of the total market for raw materials will require continuing improvements in productivity in wood-based industries and effective marketing of wood products.

2. Wood use trends differ for houses built on-site and factory-built homes

Studies of FHA-inspected houses showed that between 1959 and 1962 use of lumber, plywood, wood-based building boards, and wood shingles and shakes increased in homes built on-site. Building boards and plywood have now largely replaced lumber for sheathing and subflooring. Nonwood materials have further penetrated traditional lumber siding and flooring markets. Nevertheless lumber use per new house built on-site increased an average of 130 board feet during this three-year period to a total of approximately 10,200 board feet. This increase was primarily due to an increase in house size. Plywood use increased 30 percent between 1959 and 1962 to a total of 2,234 square feet (3/8-inch basis) per unit. Use of these wood products varied widely by construction type and among different regions of the United States. In contrast to houses built on-site, the wood content of "house packages" sold by home manufacturers has decreased in recent years, largely due to substitution of nonwood materials for siding and for some framing and millwork items.

3. Wood flooring preferred but markets limited by slab-on-ground construction

Preliminary results of recent studies indicate that most home owners prefer wood to other types of flooring and consider it the cheapest to maintain. Builders are often reluctant to use wood flooring on concrete slabs, however, because of increased installation costs or fear of poor performance. As a result, nonwood flooring materials are now widely used in new residences built on slab foundations. The percentage of new residential floor area covered with hardwood flooring has dropped from nearly 70 percent in 1955 to less than 35 percent at the present time. Findings indicate that use of wood flooring in areas where slab-on-ground construction is widely used could be increased only through development and promotion of improved and lower cost methods of installing wood floors over concrete, or by other modifications of building practices.

A related study of comparative maintenance and durability of residential floors indicates that wood floors last at least 2 to 3 times as long, and require significantly less effort and expense to maintain, than the most commonly used nonwood materials. In sample apartments in Boston, for example, time spent per square foot maintaining living room floors of exposed hardwood averaged 28 percent less than the time spent on carpeted floors, and 82 percent less than that spent on asphalt tile floors. Furthermore, the average unit cost of maintaining the wood floors, including all materials and professional care, was less than half the cost of maintaining other floor types.

4. Timber industry opportunities evaluated in selected areas of West Virginia and Minnesota

The amount, quality and cost of timber, labor, water, transportation, and other facilities or materials available in selected areas of West Virginia and Minnesota were appraised in terms of opportunities for local expansion of industries and employment. Data from these studies provide both public and private agencies and organizations with essential information on potential development and use of timber resources in these areas. The report on the West Virginia study showed that three of five areas studied have characteristics favorable to the development of an expanded lumber industry, two have advantages for particleboard production, and one is superior to the others for a woodpulp industry. This analysis also showed that prospects for the manufacture of lumber, woodpulp, and furniture parts are better than those for manufacture of particleboard and finished furniture. The Minnesota study showed that transportation cost advantages, available water resources, and other factors favored the development of fiberboard manufacturing facilities at several locations but relatively few satisfactory locations for pulp mills requiring large volumes of water. More than 6,000 persons in the area studied were actively seeking employment; most possessed technical skills, were in the younger age classes, and were relatively well educated.

5. Opportunities for reducing manufacturing costs and upgrading lumber values through improved practices

Recently completed studies of hardwood sawmilling operations in Missouri, Ohio, and Kentucky showed that sample mills averaged a daily loss of $16 from down-time, much of it avoidable, and an additional average loss of $6.40 per thousand board feet due to mismanufacture. Logs were seldom cut to produce the best combination of grades possible, and losses of potential values on some logs amounted to as much as $40 per thousand board feet. Most mill operators did not keep adequate cost records--an omission that contributed to poor cost control of mill operations and inefficiencies in management.

A study of 17 sample sawmills and concentration yards in the Appalachian region showed average losses in value of oak lumber during air-seasoning of $12 per thousand board feet. With little additional investment in roofing of lumber during drying and use of an adequate number of stickers seasoning losses could be reduced by an estimated $10 per thousand board feet.

As a result of these studies, general guides and recommendations for improving sawmilling and air-drying practices in Appalachian and Midwestern hardwood sawmills and lumber concentration yards are being prepared.

6. Wooden highway guardrail posts shown to be a good buy

A recently completed study in West Virginia showed that, contrary to common beliefs, the in-place cost of treated wood guardrail posts averaged more than 10 percent lower than the cost of steel posts now widely used. A new company formed on the basis of the findings of this study is now installing wood guardrail posts in the State. There is an abundance of suitable wood material available in the Appalachian area for the production of treated wood posts, yet few of the 25 to 30 thousand posts installed annually along West Virginia highways during recent years have been made of wood.

7. Opportunities for expanding markets for wooden pallets

With the rapid growth of mechanized materials handling, studies show that lumber consumption in pallet manufacture has increased from 830 million board feet in 1952 to 1.7 billion board feet in 1962. Pallet manufacturers have become an especially important market for Appalachian timber since the principal raw material used is the lower grades of hardwood lumber, and much of the sawtimber volume of the Appalachian area is made up of logs that will produce high proportions of those grades. Although palletized materials handling systems have been widely adopted within some industries, they are used by only a few firms in many others. Research is evaluating further opportunities for expanding the use of wooden pallets in handling, warehousing, and shipping in food products and other industries where palletized systems are not now widely used.

8. Markets for residential fencing

Studies in the Metropolitan area of St. Louis, Missouri and in three selected villages in southern Illinois showed that 3 out of 4 houses in these areas have some type of fencing associated with the property. For houses with fencing, amounts used averaged 86.5 lineal feet, but differed significantly with age of the house. In St. Louis, for example, houses less than 5 years old had an average of 33 lineal feet of fence; those 5 to 10 years old had an average of 99 feet, and those 10 years old and older had an average of 106 feet. Amounts of wood fencing used varied directly with value of residences. Continuing studies are being made to determine ways of expanding such markets for wood residential fencing.

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1964 to April 30, 1965

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES		
FS 1 1-1 (LS)	FS-LS-1101	Site requirements of northern conifers and hardwoods	St. Paul, Minnesota	I, A-2
FS 1 1-2 (LS)	FS-LS-1102	Silviculture of northern hardwoods	Marquette, Michigan	I, A-2b, A-4
FS 1 1-3 (LS)	FS-LS-1103	Silviculture of northern conifers and aspen	Grand Rapids, Minn.	I, A-5a, B-1, B-2
FS 1 1-4 (LS)	FS-LS-1104	Silviculture of mixed hardwoods	East Lansing, Mich.	
FS 1 1-5 (LS)	FS-LS-1105	Planting and plantation management of Lake States conifers	East Lansing, Mich.	I, A-5a
FS 1 1-6 (CS)	FS-CS-1101	Establishment of hardwood plantations	Ames, Iowa	I, A-8
FS 1 1-9 (CS)	FS-CS-1104	Silviculture of mixed mountain hardwood types	Berea, Kentucky	I, A-1, A-5a
FS 1 1-10 (CS)	FS-CS-1105	Silviculture of bottomland and upland mixed hardwoods	Carbondale, Illinois	I, A-2b, A-3, A-8 C-1, C-3
FS 1 1-11 (CS)	FS-CS-1106	Silviculture of oak-hickory and mixed oak types	Columbia, Missouri	
FS 1 1-12 (NE)	FS-NE-1101	Silviculture of spruce-fir and white birch	Orono, Maine	
FS 1 1-13 (NE)	FS-NE-1102	Planting and seeding of northern hardwoods	Burlington, Vermont	I, B-1, B-2
FS 1 1-14 (NE)	FS-NE-1103	Silviculture of northern Appalachian hardwoods	Parsons, W. Virginia	I, A-1, B-2
FS 1 1-15 (NE)	FS-NE-1104	Silviculture of beech-birch-maple	Durham, N. Hampshire	I, A-1, A-5a
FS 1 1-16 (NE)	FS-NE-1105	Silviculture of eastern white pine	Durham, N. Hampshire	I, A-2b
FS 1 1-17 (NE)	FS-NE-1106	Silviculture of oak-pine forests	Upper Darby, Penna.	I, A-2b
FS 1 1-19 (NE)	FS-NE-1108	Silviculture of Allegheny hardwoods	Warren, Pennsylvania	
FS 1 1-20 (SE)	FS-SE-1101	Silviculture of shortleaf and Virginia pine and hardwoods	Charlottesville, Va.	I, A-3
FS 1 1-21 (SE)	FS-SE-1102	Silviculture of southern Appalachian hardwoods	Asheville, N. Carolina	I, A-2b, B-2
FS 1 1-22 (SE)	FS-SE-1103	Silviculture and soils in relation to health and growth of trees	Durham, N. Carolina	I, B-3
FS 1 1-23 (SE)	FS-SE-1104	Physiology of flowering and seed production	Durham, N. Carolina	
FS 1 1-25 (SE)	FS-SE-1106	Silviculture of Coastal Plain timber types	Charleston, S.C.	I, A-3, A-4
FS 1 1-26 (SE)	FS-SE-1107	Silviculture of southern Piedmont hardwoods	Athens, Georgia	I, A-4, A-8, C-3
FS 1 1-27 (SE)	FS-SE-1108	Silviculture of Piedmont loblolly pine, including plantation management	Macon, Georgia	I, A-5b
FS 1 1-28 (SE)	FS-SE-1109	Southern pine seed research, tree improvement, and nursery practice	Macon, Georgia	I, A-8, C-1, C-3
FS 1 1-29 (SE)	FS-SE-1110	Silviculture of longleaf-slash pine type	Olustee, Florida	I, A-2b, A-4
FS 1 1-30 (SO)	FS-SO-1102	Artificial regeneration of southern pines	Alexandria, Louisiana	I, A-2a, A-5a, A-6
FS 1 1-31 (SO)	FS-SO-1106	Silviculture of southern hardwoods	Stoneville, Mississippi	I, A-1, C-1, C-3
FS 1 1-32 (SO)	FS-SO-1107	Silviculture of loblolly-shortleaf pine type	Crossett, Arkansas	I, A-1, A-4, A-8, C-3
FS 1 1-33 (SO)	FS-SO-1101	Silviculture of the Ozark pine type	Harrison, Arkansas	
FS 1 1-34 (SO)	FS-SO-1103	Pine regeneration on sandhills	Marianna, Florida	I, A-3

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CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES (continued)		
FS 1 1-35 (SO)	FS-SO-1104	Silviculture of east Texas pine hardwoods	Nacogdoches, Texas	I, A-2b
FS 1 1-36 (SO)	FS-SO-1105	Silviculture of Cumberland Plateau pine and hardwood types	Sewannee, Tennessee	I, A-2b
FS 1 1-37 (ITF)	FS-ITF-1101	Silviculture of tropical trees	Rio Piedras, P.R.	
FS 1 1-39 (ITF)	FS-ITF-1102	Applied tropical forestry	Rio Piedras, P.R.	
FS 1 1-38 (WO)	FS-WO-1101	Tree nutrition physiology of forest trees	Washington, D.C.	I, A-8
FS-P-2	FS-P-2	Pioneering research on physiology of wood formation	Rhinelander, Wisconsin	I, A-8
FS 1 1-40 (WO)(Gr.)	FS-WO-1102(Gr.)	Uptake, translocation, and cycling of residual pesticides by woody plants	Athens, Georgia	
		SILVICULTURE OF WESTERN FOREST TYPES		
FS 1 2-1 (NOR)	FS-NOR-1201	Silviculture of coastal forests in Alaska	Juneau, Alaska	I, A-4
FS 1 2-2 (NOR)	FS-NOR-1202	Silviculture of interior Alaska forests	College, Alaska	I, B-2
FS 1 2-3 (PNW)	FS-PNW-1201	Seeding, planting, and nursery practices in the Pacific Northwest	Portland, Oregon	
FS 1 2-5 (PNW)	FS-PNW-1203	Silviculture of lodgepole and ponderosa pines and interior mixed conifers	Bend, Oregon	I, A-5
FS 1 2-6 (PNW)	FS-PNW-1204	Silviculture of true fir-mountain hemlock and Sitka spruce-western hemlock types	Corvallis, Oregon	I, A-1, A-2a, A-4, A-8
FS 1 2-7 (PNW)	FS-PNW-1205	Silviculture of mixed pines and Douglas-fir	Roseburg, Oregon	
FS 1 2-8 (PNW)	FS-PNW-1206	Brushfield reclamation	Corvallis, Oregon	I, B-1
FS 1 2-9 (PNW)	FS-PNW-1207	Silviculture of young-growth Douglas-fir and related species	Olympia, Washington	I, A-8, B-3
FS 1 2-10 (PNW)	FS-PNW-1208	Prevention and control of animal damage to forest trees	Olympia, Washington	I, A-6
FS 1 2-12 (PSW)	FS-PSW-1201 (Rev.) (Supersedes 1201, 1202)	Silviculture of Sierra Nevada conifer types	Redding, California	I, A-2b, A-5b, A-6, A-8, C-2
FS 1 2-14 (PSW)	FS-PSW-1203	Silviculture of redwood and Douglas-fir	Arcata, California	
FS 1 2-16 (PSW)	FS-PSW-1205	Forest establishment and management	Honolulu, Hawaii	I, A-7
FS 1 2-17 (INT)	FS-INT-1201	Silviculture of western white pine	Moscow, Idaho	I, B-1, C-1
FS 1 2-18 (INT)	FS-INT-1202	Silviculture of ponderosa pine and interior Douglas-fir	Boise, Idaho	
FS 1 2-19 (INT)	FS-INT-1203	Silviculture of lodgepole pine in the northern and intermountain regions	Bozeman, Montana	I, A-3
FS 1 2-20 (INT)	FS-INT-1204	Silviculture of western larch and Engelmann spruce	Missoula, Montana	I, B-1
FS 1 2-27 (INT)	FS-INT-1205	Forest ecosystem management and protection in Northern Rocky Mountain and intermountain regions	Ogden, Utah	

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CPO	FS			
		SILVICULTURE OF WESTERN FOREST TYPES (continued)		
FS 1 2-21 (RM)	FS-RM-1201	Silviculture of spruce-fir and lodgepole pine in the central Rocky Mountains	Ft. Collins, Colorado	I, A-4
FS 1 2-22 (RM)	FS-RM-1202	Silviculture of mixed conifers and aspen	Ft. Collins, Colorado	
FS 1 2-23 (RM)	FS-RM-1203	Silviculture of ponderosa pine in the Southwest	Flagstaff, Arizona	I, B-2
FS 1 2-24 (RM)	FS-RM-1204	Windbreak establishment and management in the central and southern Great Plains	Lincoln, Nebraska	I, A-7
FS 1 2-25 (RM)	FS-RM-1205	Silviculture of Black Hills ponderosa pine	Rapid City, S. Dakota	
FS 1 2-26 (LS)	FS-LS- 1201	Shelterbelt establishment and management including tree improvement aspects	Bottineau, N. Dakota	I, A-7
		FOREST MENSURATION		
FS 1 3-1 (PNW)	FS-PNW-1301	Mensuration and related timber management techniques in the Northwest	Portland, Oregon	
FS 1 3-2 (INT)	FS-INT-1301	Mensuration and related timber management techniques in the northern Rocky Mountains	Moscow, Idaho	
FS 1 3-3 (NE)	FS-NE-1301	Mensuration studies of northeastern conifers and hardwoods	Upper Darby, Penna.	
FS 1 3-4 (SO)	FS-SO-1301	Mensuration studies of southern pines and hardwoods	Harrison, Arkansas	
FS 1 3-5 (RM)	FS-RM-1301	Mensuration and related timber management techniques in the central Rocky Mountains and Southwest	Ft. Collins, Colorado	I, B-2
FS 1 3-6 (PSW)	FS-PSW-1301 (Rev.)	Mensuration and related timber management techniques in the Pacific Southwest	Berkeley, California	I, B-2
FS 1 3-8 (CS)	FS-CS-1301	Mensuration studies of Central States hardwoods	Columbus, Ohio	I, B-2
FS 1 3-9 (SE)	FS-SE-1301	Mensuration studies of forests of the Southeast	Athens, Georgia	
FS-P-1	FS-P-1	Pioneering research unit in forest mensuration	Berkeley, California	
		FOREST GENETICS		
FS 1 4-1 (PSW)	FS-PSW-1401	Genetics of western conifers	Placerville, Calif.	I, C-1
FS 1 4-2 (LS)	FS-LS-1401	Genetics of northern conifers and hardwoods	Rhinelander, Wis.	I, C-1, C-2, C-3
FS 1 4-3 (NE)	FS-NE-1401	Breeding northeastern conifers and hardwoods	Durham, N. Hampshire	I, C-1, C-2, C-3
FS 1 4-4 (SO)	FS-SO-1401	Genetics of southern pines and hardwoods	Gulfport, Mississippi	I, A-8, C-1, C-3
FS 1 4-5 (WO)	FS-WO-1401	Identification, classification, and distribution of forest trees	Washington, D.C.	I, C-1,
FS 1 4-6 (PNW)	FS-PNW-1401	Breeding northwestern trees	Corvallis, Oregon	I, C-1
FS1 4-6 (WO) (Gr.)	FS-WO-1402 (Gr.)	Breeding pines for resistance to Neodiprion sawflies	New Haven, Conn.	

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CPO	FS			
		TIMBER-RELATED CROPS		
FS 1 5-1 (NE)	FS-NE-1501	Maple sap production and related tree improvement	Burlington, Vermont	I, D-2
FS 1 5-2 (SE)	FS-SE-1501	Naval stores gum production and physiology, and related tree improvement	Olustee, Florida	I, D-1
FS 1 5-4 (CS)	FS-CS-1501	Christmas trees and other decorative or medicinal plants	Berea, Kentucky	I, D-3
FS 1 5-3 (WO)(Gr.)	FS-WO-1501 (Gr.)	Factors influencing carbohydrate metabolism of sugar maple	Burlington, Vermont	
		PL 480 PROJECTS		
S3-FS- 2		Breeding investigations in trees with perfect flowers, as in Eucalyptus	Rio Claro, Brazil	
S3-FS- 6		Mineral nutrition of Pinus elliottii	São Paulo, Brazil	
S4-FS- 3		Investigation in rooting and growth induction of short shoots of Pinus radiata	Santiago, Chile	I, C-3
S4-FS- 6		Biosynthesis of terpenes in Pinus radiata	Santiago, Chile	
S4-FS- 7		Effect of growth substances in pine meristems	Santiago, Chile	
S5-FS- 4		Basic studies of the physiological changes in the transition from juvenile to mature stage in certain forest trees	Bogota, Colombia	
E8-FS- 1		Basic studies into the important factors controlling the quantity and quality of natural seed crops of forest trees	Helsinki, Finland	
E8-FS-31		The role of mycorrhizae	Helsinki, Finland	I, A-8
E8-FS-36		The importance of soil temperature, height of water table, and microclimate as the growth factors of pine, spruce, and birch	Helsinki, Finland	
E8-FS-43		Development of the research methods of growth and yield studies	Helsinki, Finland	I, B-1
E8-FS-44		Genetics of flowering of forest trees: The problem of fertilization	Helsinki, Finland	
E8-FS-45		Population study concerning spruce with special reference to the variation in the characteristics of wood	Helsinki, Finland	
E8-FS-46		The value of alder in adding nitrogen in forest soils	Helsinki, Finland	
E8-FS-47		Induced polyploidy and other mutations in birch, Betula spp.	Turku, Finland	
E8-FS-48		DNA and RNA studies on Scotch pine with special attention to finding a method to increase flowering	Turku, Finland	

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Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
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		PL 480 PROJECTS (continued)		
E8-FS-49		The role of soil fungi in the formation of different humus types, especially in raw humus formation in northern forests	Helsinki, Finland	
E8-FS-50		Pollen dispersal and its significance in silviculture and genetics	Helsinki, Finland	
E8-FS-51		Effect of silvicultural practices upon the arthropod, annelid, and nematode populations in forest litter and soil	Helsinki, Finland	
E11-FS-1		Reconnaissance breeding in certain hard pines of the Mediterranean area	Thessaloniki, Greece	
E11-FS-2		Nutritional studies of forest trees under various soil and nutrient solution conditions	Athens, Greece	
A7-FS-10		Investigations on mycorrhiza-forming fungi with special reference to conifers in India	Dehra Dun, India	
A7-FS-11		Investigations on the use of auxins in vegetative reproduction of forest plants	Chandigarh, India	
A7-FS-12		Cytology of some Himalayan hardwoods and cytological and morphological differences or similarities in ecotypes or clines of Himalayan forest trees	Chandigarh, India	
A7-FS-36		Tissue and cell culture of pines and allied conifers	Delhi, India	
A10-FS-5		Factors controlling the annual rhythm of wood production	Jerusalem, Israel	
A10-FS-7		Mechanisms of drought tolerance and drought avoidance in conifers of the Mediterranean zone and the arid West of the United States	Rehovot, Israel	
A10-FS-8		The development of techniques for the vegetative propagation of pine trees by means of needle fascicles	Jerusalem, Israel	
A10-FS-10		Effect of transpiration retardants on certain physiological processes of forest seedlings and other plants	Jerusalem, Israel	
A10-FS-15		Morphological and anatomical changes related to resin stimulation	Jerusalem, Israel	
E15-FS-3		Factors affecting the difficult rooting of cuttings in some poplars (i.e. Populus deltoides v. angulata, P. alba, P. tremula) and their hybrids	Rome, Italy	
E15-FS-6		The problem of incompatibility in grafting of forest trees, especially pines	Florence, Italy	
E15-FS-8		Limiting factors of the photosynthetic efficiency in a forest tree (Populus canadensis)	Milan, Italy	

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CPO	FS			
		PL 480 PROJECTS (continued)		
A13-FS-1		The fundamental mechanism of root-primordia formation of cuttings	Suwon, Korea	
E21-FS-1		Influence of soil, ground water table and precipitation on the rate of increment of Pinus sylvestris trees and stands in age classes I-III	Warsaw, Poland	
E21-FS-17		Investigations of pure culture of mycorrhizal fungi of pine (Pinus sylvestris L.)	Warsaw, Poland	
E21-FS-20		Population study of spruce in Poland	Warsaw, Poland	
E21-FS-22		Influence of sowing of lupine on tree growth	Warsaw, Poland	
E21-FS-23		Decomposition of forest litter in stands are related to degree of thinning	Warsaw, Poland	
E21-FS-24		Studies in wood formation	Warsaw, Poland	
E21-FS-26		A survey of endogenous growth substances in certain forest trees	Torun, Poland	
E21-FS-31		Studies on the variability of photosynthesis of pine trees during development under different conditions of growth	Warsaw, Poland	
E21-FS-32		Effect of gibberellin on auxin metabolism and its relation to growth of Scots pine seedlings (Pinus sylvestris)	Kornik nr. Poznan, Poland	
E21-FS-33		Variation between Picea abies provenances in their ability to utilize mineral nutrients available in limited quantities under competitive conditions	Kornik nr. Poznan, Poland	
E25-FS-14		Ontogenesis of enzymes induced in pine seed through cold stratification	Madrid, Spain	
E25-FS-15		Minor elements distribution in cellular fluids of floral and foliar tissue of trees	Madrid, Spain	
E25-FS-16		Isolation and identification of plant hormones associated with callus and root formation	Santiago, Spain	
E25-FS-20		The determination of levels of boron, manganese, and molybdenum sufficient for growth of Monterey pine (Pinus radiata) and the characterization of deficiency symptoms for these three elements	Madrid, Spain	
E25-FS-23		Spanish contribution to multilingual forest terminology with Hispano-American terms	Madrid, Spain	
A6-FS-2		The genus Abies	Taipei, Taiwan	

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		FOREST SOIL AND WATER RESEARCH		
FS 1 6-1 (NOR)	FS-NOR-1601	Erosion and sedimentation, coastal forests	Juneau, Alaska	
FS 1 6-2 (PNW)	FS-PNW-1601	Water yield and erosion - Columbia River	Wenatchee, Washington	II, A-2-a
FS 1 6-3 (PNW)	FS-PNW-1602	Watershed logging methods and streamflow - western Cascades	Corvallis, Oregon	II, A-1-c
FS 1 6-4 (PSW)	FS-PSW-1601	Snow management research	Berkeley, California	II, A-1-b
FS 1 6-5 (PSW)	FS-PSW-1602	Water source hydrology	Berkeley, California	II, A-2-a
FS 1 6-6 (PSW)	FS-PSW-1603	Water yield - lower conifer	Berkeley, California	II, A-1-b
FS 1 6-7 (PSW)	FS-PSW-1604	Flood and sediment - Southwest	Glendora, California	II, A-3-d
FS 1 6-8 (PSW)	FS-PSW-1605	Water yield - Southwest	Glendora, California	II, A-3-d
FS 1 6-10 (INT)(R)	FS-INT-1601(Rev.)	Snowmelt flood and sediment reduction	Moscow, Idaho	II, A-2-b
FS 1 6-11 (INT)	FS-INT-1602	Soil stabilization, logging, northern Rockies	Boise, Idaho	II, A-2-a
FS 1 6-12 (INT)(R)	FS-INT-1603(Rev.)	Watershed rehabilitation and protection - high rangelands	Logan, Utah	II, A-2-c, A-3-b
FS 1 6-14 (INT)(R)	FS-INT-1605(Rev.)	Water yield improvement - Great Basin and Missouri	Logan, Utah	II, A-1-b
FS 1 6-16 (RM)	FS-RM-1601	Alpine snow and avalanche research	Fort Collins, Colorado	II, A-1-a
FS 1 6-17 (RM)	FS-RM-1602	Water yield snowpack timber - Rocky Mountains	Fort Collins, Colorado	II, A-1-b, A-3-b
FS 1 6-18 (RM)(R)	FS-RM-1603(Rev.)	Water yield, soil stabilization - Big Horn, North Platte	Laramie, Wyoming	II, A-1-a
FS 1 6-19 (RM)	FS-RM-1604	Watershed rehabilitation - Southwest	Albuquerque, New Mexico	II, A-3-b
FS 1 6-20 (RM)	FS-RM-1605	Riparian and wet sites	Tempe, Arizona	II, A-1-b
FS 1 6-21 (RM)	FS-RM-1606	Water yield upland areas	Tempe, Arizona	II, A-1-b
FS 1 6-22 (LS)	FS-LS-1601	Runoff and erosion reduction - nonglaciated	La Crosse, Wisconsin	II, A-3-a
FS 1 6-23 (LS)	FS-LS-1602	Bog and swamp hydrology	Grand Rapids, Minnesota	II, A-4-a
FS 1 6-24 (LS)	FS-LS-1603	Ground water hydrology and streambank erosion	Cadillac, Michigan	II, A-1-b
FS 1 6-25 (CS)	FS-CS-1601	Strip mined area restoration	Berea, Kentucky	II, A-3-c
FS 1 6-26 (CS)	FS-CS-1602	Management of storm runoff	Columbus, Ohio	II, A-2-a
FS 1 6-27 (NE)(R)	FS-NE-1601(Rev.)	Water yield improvement - New England	Laconia, New Hampshire	II, A-2-a
FS 1 6-28 (NE)(R)	FS-NE-1602(Rev.)	Floods, erosion and water yield - central Appalachians	Parsons, West Virginia	II, A-1-c
FS 1 6-29 (NE)	FS-NE-1603	Municipal watersheds	Upper Darby, Pa.	II, A-1-c
FS 1 6-30 (NE)	FS-NE-1604	Stream regimen and water yields - Northeast	Syracuse, New York	II, A-1-c
FS 1 6-31 (SE)	FS-SE-1601	Water yield improvement, mountains - Piedmont	Franklin, N. C.	II, A-1-c, A-4-a
FS 1 6-32 (SE)	FS-SE-1602	Wetland improvement	Charleston, S. C.	
FS 1 6-34 (SO)	FS-SO-1601	Water timing - Ozark-Ouachita	Harrison, Arkansas	II, A-3-a

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CPO	FS			
		FOREST SOIL AND WATER RESEARCH		
FS 1 6-35 (SO)	FS-SO-1602	Coastal Plain hydrology - South	Oxford, Mississippi	II, A-3-a
FS 1 6-36 (SO)	FS-SO-1603	Watershed rehabilitation - Coastal Plain	Oxford, Mississippi	
FS 1 6-37 (SO)	FS-SO-1604	Management of erosive watersheds	Oxford, Mississippi	
FS 1 6-38 (RM)	FS-RM-1608	Water yield, soil stabilization	Rapid City, S. Dakota	
		P. L. 480 PROJECTS		
	A10-FS-9	Monographic revision of the genus Tamarix	Israel	II, A-5-a
	A10-FS-13	Study of difference in effects of forest and other vegetative covers on water yield	Israel	II, A-5-b
		FOREST RECREATION RESEARCH		
FS 1 9-1 (PSW)(R)	FS-PSW-1901(Rev.)	Recreation Management Guides - California	Berkeley, California	II, B-1, 3
FS 1 9-2 (LS)	FS-LS-1901	Recreation - LS	St. Paul, Minnesota	II, B-2, 3
FS 1 9-3 (LS)	FS-LS-1902	Forest recreation unit in cooperation with University of Michigan	Ann Arbor, Michigan	II, B-2, 3
FS 1 9-4 (CS)	FS-CS-1901	Small Woodland Recreation	Columbus, Ohio	II, B-2, 3
FS 1 9-5 (NE)	FS-NE-1901	Recreation Research in the Northeast	Warren, Pennsylvania	II, B-1, 2, 3
FS 1 9-6 (NE)	FS-NE-1902	Syracuse Recreation Project	Syracuse, New York	II, B-2, 3
FS 1 9-7 (WO)	FS-WO-1901	Evaluation of economic and other factors pertinent to planning and administering forest recreation use	Washington, D. C.	
FS 1 9-8 (INT)	FS-INT-1901	Recreation Planning and Management, INT	Ogden, Utah	II, B-2, 3
FS 1 9-9 (INT)	FS-INT-1902	Forest Recreation Research Unit in Cooperation with Utah State University	Logan, Utah	II, B-1
FS 1-9-11 (PNW)	FS-PNW-1901	Wilderness Recreation Dynamics	Portland, Oregon	II, B-2, 3
FS 1 9-13 (SE)	FS-SE-1901	Forest Recreation Management	Asheville, N. C.	II, B-1, 2
FS 1 9-15 (RM)	FS-RM-1901	Forest Recreation Research-Rocky Mountains	Fort Collins, Colorado	II, B-1, 2
FS 1 9-16 (WO)(GR)	FS-WO-1902(GR)	Some effects of landscape enhancement on timber production	Cambridge, Mass.	

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CPO	FS			
		RANGE MANAGEMENT RESEARCH		
FS 1 7-1 (PNW)	FS-PNW-1701	Range ecology and management - Northwest	La Grande, Oregon	II, C-1-a, 2-a, 3-a
FS 1 7-4 (PSW)	FS-PSW-1702	Management of annual plant and related ranges	Fresno, California	II, C-3-a
FS 1 7-5 (PSW)	FS-PSW-1703	Management of bunchgrass range	Berkeley, California	
FS 1 7-7 (INT)	FS-INT-1701	Sagebrush, cheatgrass, and granitic soil ranges	Boise, Idaho	II, C-1-a, 2-a, 3-a
FS 1 7-8 (INT)	FS-INT-1702	Northern Rocky Mountain grasslands	Bozeman, Montana	II, C-5
FS 1 7-9 (INT)	FS-INT-1703	Salt-desert shrub, sagebrush-grass, and pinyon-juniper ranges	Provo, Utah	II, C-3-a, 3-b
FS 1 7-10 (INT)	FS-INT-1704	Management of mountain herbland, brushland and aspen ranges	Logan, Utah	II, C-1-a
FS 1 7-11 (RM)	FS-RM-1701	Mountain ranges - central Rockies	Fort Collins, Colorado	II, C-1-a, 2-a, 2-c
FS 1 7-12 (RM)	FS-RM-1702	Range biometry	Fort Collins, Colorado	
FS 1 7-13 (RM)	FS-RM-1703	Alpine and subalpine ranges	Laramie, Wyoming	II, C-1-a
FS 1 7-14 (RM)	FS-RM-1704	Southwestern seeded ranges	Albuquerque, New Mexico	II, C-1-a, 2-b
FS 1 7-15 (RM)	FS-RM-1705	Southwestern chaparral, woodland, and forest ranges	Flagstaff, Arizona	II, C-1-a, 4
FS 1 7-16 (RM)	FS-RM-1706	Semidesert cattle ranges	Tucson, Arizona	II, C-3-a
FS 1 7-17 (CS)	FS-CS-1701	Range evaluation and management	Columbia, Missouri	II, C-1-a, 3-a, 3-b, 4; II, D-1, 2
FS 1 7-18 (SE)	FS-SE-1701	Integrated range-timber-wildlife management	Fort Myers, Florida	II, C-4
FS 1 7-19 (SO)	FS-SO-1701	Southern pine cattle ranges	Alexandria, Louisiana	II, C-3-a, 4
FS 1 7-20 (WO)	FS-WO-1701	Range plant taxonomy	Washington, D. C.	
FS 1 7-21 (WO)	FS-WO-1702	Range inventory and evaluation	Washington, D. C.	
		P. L. 480 PROJECTS		
	A10-FS-6	Germination of seeds of desert plants	Israel	II, C-1-a
	E25-FS-1	Studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions	Spain	

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CPO	FS			
		WILDLIFE HABITAT RESEARCH		
FS 1 8-1 (PNW)	FS-PNW-1801	Big-game habitat - Pacific Northwest	La Grande, Oregon	II, D-2
FS 1 8-3 (PSW)	FS-PSW-1801	Deer habitat - California	Berkeley, California	II, D-2, C-2-b
FS 1 8-4 (INT)	FS-INT-1801	Deer winter range - Idaho	Boise, Idaho	II, D-2, C-5
FS 1 8-5 (INT)	FS-INT-1802	Northern Rockies forest wildlife habitat	Missoula, Montana	II, D-2, C-2-b
FS 1 8-6 (INT)	FS-INT-1803	Game range restoration, and wildlife livestock relations	Provo, Utah	II, D-1, 2
FS 1 8-7 (RM)	FS-RM-1801	Forest game and fish habitat - central Rockies	Fort Collins, Colorado	II, D-2
FS 1 8-8 (RM)	FS-RM-1802	Wildlife habitat - southwestern vegetation types	Tempe, Arizona	II, D-1, 2
FS 1 8-9 (RM)	FS-RM-1803	Wildlife habitat - Black Hills	Rapid City, South Dakota	II, D-2
FS 1 8-11 (LS)	FS-LS-1801	Conifer-aspen wildlife habitat - Lake States	St. Paul, Minnesota	II, D-2
FS 1 8-13 (NE)	FS-NE-1801	Wildlife habitat in northeastern forests	Warren, Pennsylvania	II, D-1
FS 1 8-15 (SE)	FS-SE-1801	Forest wildlife habitat in the Southeast	Asheville, North Carolina	II, D-1, 2
FS 1 8-16 (SO)	FS-SO-1801	Wildlife habitat in southern forests	Nacogdoches, Texas	
		P. L. 480 PROJECTS		
	E21-FS-30	The quantity, quality and seasonal variation of food resources available to red deer in various environmental conditions of forest management		

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CPO	FS			
		FOREST FIRE		
FS 2 1-1 (NOR)	FS-NOR-2101	Fire control systems	College, Alaska	III A, 1-b
FS 2 1-2 (PNW)	FS-PNW-2101	Fire control and use	Portland, Oregon	----
FS 2 1-3 (PNW)	FS-PNW-2102	Fire weather	Portland, Oregon	III A, 1-c
FS 2 1-4 (PSW)	FS-PSW-2101	Conflagration control	Riverside, California	III A, 3-c
FS 2 1-5 (PSW)	FS-PSW-2102	Fire control systems	Riverside, California	III A, 3-b
FS 2 1-6 (PSW)	FS-PSW-2103	Fire chemistry	Berkeley, California	III A, 1-a
FS 2 1-7 (PSW)	FS-PSW-2104	Fuel break	Riverside, California	III A, 3-b
FS 2 1-8 (PSW)	FS-PSW-2105	Fire prevention	Berkeley, California	III A, 2-a
FS 2 1-9 (PSW)	FS-PSW-2106	Improvement of fire control methods	Riverside, California	III A, 3-b,c
FS 2 1-10(PSW)	FS-PSW-2107	Fire behavior	Riverside, California	III A, 1-c,d
FS 2-1-12(INT)	FS-INT-2101	Project skyfire	Missoula, Montana	III A, 2-b
FS 2 1-13(INT)	FS-INT-2102	Fire control systems	Missoula, Montana	III A, 3-a,c
FS 2 1-14(INT)	FS-INT-2103	Fire physics	Missoula, Montana	III A, 1-a
FS 2 1-15(INT)	FS-INT-2104	Fire behavior	Missoula, Montana	III A, 1-b
FS 2 1-16(RM)	FS-RM- 2101	Fire control	Fort Collins, Colorado	----
FS 2 1-17(RM)	FS-RM- 2102	Fire use	Flagstaff, Arizona	III A, 1-b
FS 2 1-18(LS)	FS-LS- 2101	Fire control systems	St. Paul, Minnesota	III A, 3-b
FS 2 1-20(SE)	FS-SE- 2101	Fire use	Macon, Georgia	III A, 4-a,b
FS 2 1-21(SE)	FS-SE- 2102	Fire control	Macon, Georgia	III A, 3-c
FS 2 1-22(SE)	FS-SE- 2103	Fire potential	Macon, Georgia	----
FS 2 1-23(SE)	FS-SE- 2104	Fire environment	Macon, Georgia	----
FS 2 1-24(SE)	FS-SE- 2105	Fire models	Macon, Georgia	III A, 1-a
FS 2 1-25(CS)	FS-CS- 2101	Hardwood fire control	Columbia, Missouri	III A, 1-c
FS 2 1-26(SO)	FS-SO- 2101	Fuels and fire control	Alexandria, Louisiana	----
FS 2 1-27(SO)	FS-SO- 2102	Fire prevention	Alexandria, Louisiana	III A, 2-a
FS 2 1-28(WO)	FS-WO- 2101	National fire danger rating	Asheville, N.C.	----
		P. L. 480 PROJECTS		
E25-FS-13		Open fires and transport of fire brands	Madrid, Spain	1-a

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CPO	FS			
		FOREST INSECTS		
FS 2 2-1 (NOR)	FS-NOR-2201	Forest insects, coastal forests	Juneau, Alaska	III, B-4-b
FS 2 2-3 (PNW)	FS-PNW-2201	Bark beetles, sucking insects, cone and seed insects, wood products insects	Portland, Oregon	III, B-1-a, 4-a, 4-e
FS 2 2-4 (PNW)	FS-PNW-2202	Defoliating insects, regeneration insects, range insects	Portland, Oregon	III, B-1-a, 1-d, 4-b
FS 2 2-5 (PNW)	FS-PNW-2203	Diseases of western forest insects	Corvallis, Oregon	III, B-1-d
FS 2 2-6 (PNW)	FS-PNW-2204	Physiology and biochemistry of western forest insects	Corvallis, Oregon	III, B-4-a, 4-b
FS 2 2-7 (PNW)	FS-PNW-2205	Biological control of western forest insects	Corvallis, Oregon	III, B-1-a
FS 2 2-8 (PSW)	FS-PSW-2201	Toxicology, physiology and host resistance of forest insects in California	Berkeley, California	III, B-1-c, 1-e, 2-b, 4-a, 4-c, 4-e
FS 2 2-9 (PSW)	FS-PSW-2202	Biology, ecology and control of forest insects in California and Hawaii	Berkeley, California	III, B-2-b
FS 2 2-11(RM)	FS-RM-2201	Biology, ecology and control of forest insects in Central Rockies and southern Great Plains	Ft. Collins, Colorado	III, B-1-a, 1-b, 1-c, 1-e, 2-b, 4-a, 4-b
FS 2 2-12(RM)	FS-RM-2202	Biology, ecology and control of forest insects in the Southwest	Albuquerque, New Mexico	III, B-1-d, 4-a
FS 2 2-13(INT)	FS-INT-2201	Biology, ecology and control of forest and range browse insects in Intermountain region	Ogden, Utah	III, B-4-a
FS 2 2-14(INT)	FS-INT-2202	Biology, ecology and control of bark beetles in Northern Rockies	Missoula, Montana	III, B-4-a
FS 2 2-15(INT)	FS-INT-2203	Biology, ecology and control of defoliators and regeneration insects in Northern Rockies	Missoula, Montana	III, B-1-a, 2-b, 4-b
FS 2 2-16(LS)	FS-LS-2201	Seed and cone, aspen and shelterbelt insects in the Lake States and northern Great Plains	St. Paul, Minnesota	III, B-4-c
FS 2 2-17(LS)	FS-LS-2202	Biology, ecology and control of forest insect defoliators in the Lake States	St. Paul, Minnesota	III, B-1-a, 2-b, 4-b
FS 2 2-18(LS)	FS-LS-2203	Biology, ecology, and control of forest plantation insects in the Lake States	East Lansing, Michigan	III, B-4-d
FS 2 2-19(CS)	FS-CS-2201	Biology, ecology and silvicultural control of insects of forest and plantation insects in Central States	Delaware, Ohio	III, B-4-c, 4-d, 4-e
FS 2 2-20(CS)	FS-CS-2202	Physiology, toxicology and control of forest and shade trees in Central States	Delaware, Ohio	III, B-1-e, 2-a
FS 2 2-21(CS)	FS-CS-2203	Biological control and disease vectors	Delaware, Ohio	III, B-1-e, 4-a
FS 2 2-22(NE)	FS-NE-2201	Biology and ecology of forest insects in the Northeast	New Haven, Connecticut	III, B-1-a, 4-b, 4-e
FS 2 2-23(NE)	FS-NE-2202	Biotic control of forest insect pests in Northeast	New Haven, Connecticut	III, B-1-b
FS 2 2-24(NE)	FS-NE-2203	Control of forest insects using synthetic chemicals	New Haven, Connecticut	III, B-2-a
FS 2 2-25(SE)	FS-SE-2201	Biology, ecology, control of defoliators and sucking insects in the Southeast	Asheville, North Carolina	III, B-1-a, 2-b, 4-b

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CPO	FS			
		FOREST INSECTS		
FS 2 2-26(SE)	FS-SE-2202	Physiology and biochemistry of forest insects	Durham, North Carolina	III, B-4-a
FS 2 2-27(SE)	FS-SE-2203	Slash and longleaf seed and cone insects and insects affecting plantations and Naval Stores	Olustee, Florida	III, B-2-b, 4-c, 4-d
FS-2 2-28(SE)	FS-SE-2204	Hardwood insects; insect enemies of pines in nurseries and plantations other than slash and longleaf	Athens, Georgia	III, B-4-d
FS 2 2-30(SO)	FS-SO-2202	Biology, ecology and control of hardwood insects in Deep South	Stoneville, Mississippi	III, B-1-e, 2-a
FS 2 2-31(SO)	FS-SO-2201	Biology, ecology and control of wood products insects	Gulport, Mississippi	III, B-5-a
FS 2 2-32(SO)	FS-SO-2203	Biology, ecology and control of pine insects in Deep South	Alexandria, Louisiana	III, B-1-a, 1-b, 2-a, 2-b, 4-a
FS 2 2-33(WO)	FS-WO-2201	Aerial survey techniques research	Beltsville, Maryland	III, B-6-a
FS 2 2-34(WO)	FS-WO-2202	Aerial applications research	Beltsville, Maryland	III, B-2-b
FS 2 2-35(WO)	FS-WO-2203	Toxicology, pathology and physiology of forest insects	Beltsville, Maryland	III, B-1-d
FS 2 2-36 (WO) (C)	FS-WO-2204 (C)	Isolation, identification and synthesis of pheromones of bark beetles	Menlo Park, California	III, B-1-c
FS 2 2-37 (WO)(Gr)	FS-WO-2205 (Gr)	Role of chemical messengers in the biology of western bark beetles	Berkeley, California	----
FS 2 2-38 (WO)(Gr)	FS-WO-2206 (Gr)	Inducing sexual sterility in the European pine shoot moth	Pullman, Washington	----
FS 2 2-39 (WO)(Gr)	FS-WO-2207 (Gr)	Nutritional and developmental requirements of the European pine shoot moth	Pullman, Washington	----
FS 2 2-40 (WO)(Gr)	FS-WO-2208 (Gr)	Population dynamics of the jack pine budworm	Ann Arbor, Michigan	----
FS 2 2-41 (WO)(Gr)	FS-WO-2209 (Gr)	Factors influencing the attraction, movement, and concentration of southern bark beetles	Durham, North Carolina	----
FS 2 2-42 (WO)(Gr)	FS-WO-2210 (Gr)	Chemical investigation of host plant selection by the elm bark beetle	Columbus, Ohio	----
FS 2 2-43 (WO)(Gr)	FS-WO-2211 (Gr)	Investigations of the microflora of healthy and diseased gypsy moth larvae	Storrs, Connecticut	----
		P. L. 480 PROJECTS		
A6-FS-4		Biological study of the more important insect pests attacking genus Pinus introduced from USA	Taiwan, China	III-B-4-f-(1)a
A7-FS-6		Accelerated laboratory investigations on natural resistance of woods to termites	Dehra Dun, India	III-B-5-b-(1)a
A7-FS-7		Survey for natural enemies of Chermes spp. attacking silver fir and spruce in the Himalayas	Bangalore, India	III-B-1-f-(1)a

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CPO	FS			
		FOREST INSECTS		
		P. L. 480 PROJECTS		
A7-FS-8		Survey of parasites for gypsy moth	Bangalore, India	III-B-1-f-(1)b
A7-FS-25		Survey for natural enemies of Hypsipyla spp. in India	Bangalore, India	III-B-1-f-(1)c
A17-FS-1		Survey of insect fauna of the forests of Pakistan	Peshawar, West Pakistan	III-B-4-f-(2)a
A17-FS-5		Investigations on the predators of Adelges (an aphid on fir)	Rawalpindi, Pakistan	III-B-1-f-(2)a
A17-FS-6		Studies on the natural enemies of insect pests of West Pakistan forests	Rawalpindi, Pakistan	III-B-1-f-(2)b
A17-FS-9		Biology and ecology of important predators of spruce and fir aphids in Pakistan	Rawalpindi, Pakistan	III-B-1-f-(2)c
E8-FS-38		Orienting stimuli guiding insect pests of forests to suitable host trees	Helsinki, Finland	III-B-1-f-(3)a
E8-FS-53		A study of the biology of wood wasps (Siricidae) and their development in different kinds of roundwood and lumber	Helsinki, Finland	III-B-4-f-(3)a
E8-FS-63		Discovery and study of chemical substances in the bark of Pinus silvestris which are attractive to the bark beetle, Blastophagus piniperda L.	Helsinki, Finland	III-B-1-f-(3)b
E21-FS-2		Insects noxious to young stands of pine	Warsaw, Poland	III-B-4-f-(4)a
E21-FS-3		Research on the growth and development and disease susceptibility of some species of trees from the U.S.A. to be planted in certain climatic regions of Poland	Warsaw, Poland	III-B-4-f-(4)b
E21-FS-6		Investigations into the activity of the parasite, Trichogramma embryophagum (Hart) introduced into the forest environment with special attention to its capacity for spreading	Poznan, Poland	III-B-1-f-(4)a
E21-FS-7		Studies in the development of improved strains of parasites of forest insects	Poznan, Poland	III-B-f-(4)b
E21-FS-38		Studies on the ecology and biology of the more important parasites of Rhyacionia buoliana Schiff. in Poland	Warsaw, Poland	III-B-1-f-(4)c
E25-FS-3		Pests of poplars and preventive and curative methods of control	Madrid, Spain	III-B-4-f-(5)a
E25-FS-10		The study of parasites, predators and diseases of the Gypsy Moth and the possibility of their application in the biological control	Madrid, Spain	III-B-1-f-(5)a

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CPO	FS			
		FOREST INSECTS		
		P. L. 480 PROJECTS		
E30-FS-2		Study of the polyhedral virus disease of the gypsy moth	Zemun, Yugoslavia	III-B-1-f-(6)a
S3-FS-7		Disease and insect susceptibility and species adaptability of some North American pine species planted in Sao Paulo	Sao Paulo, Brazil	III-B-4-f-(6)a
S5-FS-1		Disease and insect susceptibility and species adaptability of some North American forest tree species planted in Colombia	Medellin, Colombia	III-B-4-f-(7)a
S9-FS-1		Disease and insect susceptibility and species adaptability of North American conifers planted in Uruguay	Montevideo, Uruguay	III-B-4-f-(8)a

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CPO	FS			
		FOREST DISEASE		
FS 2 3-1 (PNW)(R)	FS-PNW-2301(R) Supersedes 2301 and 2304	Diseases reducing forest production	Portland, Oregon	III C, 3-b
FS 2 3-2 (PNW)(R)	FS-PNW-2302(R) Supersedes 2302 and 2303	Root diseases and soil microbiology	Corvallis, Oregon	III C, 2-c, 2-d
FS 2 3-5 (PSW)(R)	FS-PSW-2301(R) Supersedes 2301 and 2302	Diseases - California and Hawaii	Berkeley, California	III C, 1-a,1-b, 3-b, 3-e
FS 2 3-7 (INT)	FS-INT-2301	Native rusts of western conifers	Logan, Utah	III C, 3-a, 3-b
FS 2 3-8 (INT)	FS-INT-2302	Breeding western white pine resistant to blister rust	Moscow, Idaho	III C, 3-b
FS 2 3-9 (INT)	FS-INT-2303	Diseases of western white pine and antibiotic action	Moscow, Idaho	III C, 3-b, 3-d
FS 2 3-10 (RM)(R)	FS-RM-2301(R) Supersedes 2301 in part	Diseases of trees and shrubs in the Central Rocky Mountains	Fort Collins, Colorado	III C, 3-d, 3-e, 4-d, 4-e, 6-c
FS 2 3-11 (RM)	FS-RM-2302	Diseases of southwest ponderosa pine and associated species	Albuquerque, New Mexico	III C, 2-d, 3-b
FS 2 3-12 (LS)	FS-LS-2301	Diseases of northern conifers	St. Paul, Minnesota	III C, 3-a, 3-b, 3-d, 4-e
FS 2 3-13 (LS)	FS-LS-2302	Diseases of aspen	St. Paul, Minnesota	III C, 3-d
FS 2 3-14 (LS)	FS-LS-2303	Diseases of northern hardwoods	Marquette, Michigan	III C, 2-d, 3-d, 3-f, 5-b
FS 2 3-15 (CS)	FS-CS-2301	Parasitic diseases and heartrots	Delaware, Ohio	III C, 2-a, 3-f, 5-a
FS 2 3-16 (CS)	FS-CS-2302	Physiogenic diseases	Delaware, Ohio	III C, 4-a
FS 2 3-17 (NE)	FS-NE-2301	Mid-Atlantic tree diseases	Upper Darby, Pennsylvania	III C, 3-d, 5-b
FS 2 3-18 (NE)	FS-NE-2302	New England tree diseases	New Haven, Connecticut	III C, 3-d, 3-f, 5-b
FS 2 3-20 (SE)(R)	FS-SE-2302(R)	Annosus root rot	Durham, North Carolina	III C, 2-a
FS 2 3-21 (SE)(R)	FS-SE-2303(R) Supersedes 2301 and 2303	Rusts, nursery and hardwood diseases	Asheville, North Carolina	III C, 2-a, 3-a, 3-c
FS 2 3-22 (SE)(R)	FS-SE-2304(R)	Soil-borne organisms	Athens, Georgia	III C, 2-b, 2-d, 2-e
FS 2 3-23 (SE)	FS-SE-2305	Air pollution	Asheville, North Carolina	III C, 4-b
FS 2 3-24 (SO)	FS-SO-2301	Wood decay	New Orleans, Louisiana	III C, 6-b
FS 2 3-25 (SO)	FS-SO-2303	Southern pine diseases	Gulfport, Mississippi	III C, 3-c, 4-e, 5-b
FS 2 3-26 (SO)	FS-30-2302	Bottomland hardwood diseases	Stoneville, Mississippi	III C, 3-d, 3-f, 6-c
FS 2 3-27 (WO)	FS-WO-2301	Cultural characteristics of forest fungi	Laurel, Maryland	III C, 6-e
FS 2 3-28 (RM)	FS-RM-2303	Diseases of field windbreaks and nurseries in the Great Plains	Lincoln, Nebraska	III C, 3-b, 3-d
FS 2 3-29 (WO)(Gr)	FS-WO-2303(Gr)	Aerobiology of piedmont forest fungi	Durham, North Carolina	III C, 2-a
FS 2 3-30 (WO)(Gr)	FS-WO-2302(Gr)	Biochemistry of wood deterioration	Durham, North Carolina	III C, 6-a
FS 2 3-31 (WO)(Gr)	FS-WO-2304(Gr)	White pine blister rust resistance	Madison, Wisconsin	----

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CPO	FS			
		FOREST DISEASE		
		P. L. 480 PROJECTS		
A6-FS-3		Important epidemic diseases of forest trees in Taiwan	Taipei, Taiwan	III C, 1-a, 2-b, 4-c, 4-e, 5-b, 7-a
A7-FS-5		Accelerated laboratory investigations of durability of wood	Dehra Dun, India	III C, 6-d
A7-FS-28		Biochemical studies of the Loranthaceae	Lucknow, India	III C, 7-a
E15-FS-5		Biology and epidemiology of pine twist rust	Florence, Italy	III C, 4-d
E21-FS-21		Forest tree seed disease organisms	Warsaw, Poland	III C, 1-a
E21-FS-35		Saprophytic and semi-parasitic fungi as an environmental factor in the forest influencing the destructive activity of Armillaria mella and Fomes annosus	Poznan, Poland	III C, 2-a, 2-b
E21-FS-37		Occurrence and impact of diseases and insects of U.S. trees planted in certain climatic regions of Poland	Warsaw, Poland	III C, 1-c
E25-FS-5		Diseases of native fir, pine, and introduced Pinus radiata acclimatized in Spain	Madrid, Spain	III C, 7-a
S3-FS-7		Disease susceptibility of some North American tree species in Sao Paulo	Sao Paulo, Brazil	III C, 1-c
S5-FS-1		Disease susceptibility of some North American tree species in Colombia	Medellin, Colombia	III C, 1-c
S9-FS-1		Disease susceptibility of some North American tree species in Uruguay	Montevideo, Uruguay	III C, 1-c

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Work and Line Project Number CPO	Work and Line Project Number FS	Work and Line Project Titles	Work Locations	Line Projects Summary Index
		WOOD QUALITY RESEARCH		
FS 3 1-1 (FPL)	FS-FPL-3101	Wood structure and identification	Madison, Wisconsin	
FS 3 1-2 (FPL)	FS-FPL-3102	Fine wood structure	Madison, Wisconsin	
FS 3 1-3 (FPL)	FS-FPL-3103	Wood structure-wood property relations	Madison, Wisconsin	IV, A-1-c
FS 3 1-4 (FPL)	FS-FPL-3104	Environmental, growth, and silvicultural effects	Madison, Wisconsin	IV, A-1-d
FS 3 1-5 (FPL)	FS-FPL-3105	Wood quality evaluation and genetic effects	Madison, Wisconsin	IV, A-1-b
FS 3 1-6 (FPL)	FS-FPL-3106	Log and tree grade development	Madison, Wisconsin	IV, A-1-a
FS 3 1-7 (FPL)	FS-FPL-3107	Lumber quality yield development	Madison, Wisconsin	
FS 3 1-8 (FPL)	FS-FPL-3108	Sawmill improvement	Madison, Wisconsin	IV, A-1-e
FS 3 1-9 (PNW)	FS-PNW-3101	Douglas-fir (and associated species) log and tree grades	Portland, Oregon	IV, A-1-a
FS 3 1-10(PSW)	FS-PSW-3101	Western pine (and associated species) log and tree grades	Berkeley, California and Ft. Collins, Colorado	IV, A-1-a
FS 3 1-11(CS)	FS-CS-3101	Hardwood log and tree grades	Columbus, Ohio	IV, A-1-a
FS 3 1-12(NE)	FS-NE-3101	Northern softwoods log and tree grades	Upper Darby, Pa.	IV, A-1-a
FS 3 1-13(SE)	FS-SE-3101	Southern softwoods log and tree grades	Asheville, N. Carolina	IV, A-1-a
		SOLID WOOD PRODUCTS RESEARCH		
FS 3 2-1 (FPL)	FS-FPL-3201	Machining and veneer cutting	Madison, Wisconsin	IV, A-2-a
FS 3 2-2 (FPL)	FS-FPL-3202	Product and process development	Madison, Wisconsin	IV, A-2-b
FS 3 2-3 (FPL)	FS-FPL-3203	Wood drying	Madison, Wisconsin	IV, A-2-c
FS 3 2-4 (FPL)	FS-FPL-3204	Glues and gluing processes	Madison, Wisconsin	IV, A-2-d
FS 3 2-5 (FPL)	FS-FPL-3205	Glued wood products	Madison, Wisconsin	IV, A-2-e
FS 3 2-6 (FPL)	FS-FPL-3206	Wood finishing	Madison, Wisconsin	IV, A-2-f
FS 3 2-7 (FPL)	FS-FPL-3207	Fire performance of wood	Madison, Wisconsin	IV, A-2-g
FS 3 2-8 (FPL)	FS-FPL-3208	Environmental effects	Madison, Wisconsin	
FS 3 2-9 (FPL)	FS-FPL-3209	Preservative development and treating processes	Madison, Wisconsin	IV, A-2-h
FS 3 2-10(FPL)	FS-FPL-3210	Wood fungus and insects effects and control	Madison, Wisconsin	III, C-6-b, C-6-e
		WOOD FIBER PRODUCTS RESEARCH		
FS 3 3-1 (FPL)	FS-FPL-3301	Pulping process investigations	Madison, Wisconsin	IV, A-3-a
FS 3 3-2 (FPL)	FS-FPL-3302	Pulp properties	Madison, Wisconsin	IV, A-3-b
FS 3 3-3 (FPL)	FS-FPL-3303	Fiber processing	Madison, Wisconsin	IV, A-3-c
FS 3 3-4 (FPL) (R)	FS-FPL-3304 (Rev.) supersedes 3304 and 3305 in part	Papermaking and converting processes	Madison, Wisconsin	IV, A-3-d

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Work and Line Project Number CPO	Work and Line Project Number FS	Work and Line Project Titles	Work Locations	Line Projects Summary Index
FS 3 3-6 (FPL)	FS-FPL-3306 supersedes 3305 in part	Fundamental properties of paper	Madison, Wisconsin	IV, A-3-e
		WOOD CHEMISTRY RESEARCH		
FS 3 4-1 (FPL)	FS-FPL-3401	Wood carbohydrates and conversion products	Madison, Wisconsin	
FS 3 4-2 (FPL)	FS-FPL-3402	Lignin structure and utilization	Madison, Wisconsin	IV, A-4-a
FS 3 4-3 (FPL)	FS-FPL-3403	Chemistry of wood and bark extractives	Madison, Wisconsin	IV, A-4-b
FS 3 4-4 (FPL)	FS-FPL-3404	Biochemistry of wood constituents	Madison, Wisconsin	
FS 3 4-5 (FPL)	FS-FPL-3405	Surface and polymer chemistry of wood	Madison, Wisconsin	IV, A-4-c
FS 3 4-6 (FPL)	FS-FPL-3406	Process development	Madison, Wisconsin	
FS 3 4-7 (FPL)	FS-FPL-3407	Analytical development, instrumentation, and service	Madison, Wisconsin	IV, A-4-d
FS 3 4-8 (WO) (GR)	FS-WO-3401 (GR)	The chemistry and ultra-structure of reaction wood	Syracuse, New York	
		WOOD ENGINEERING RESEARCH		
FS 3 5-1 (FPL)	FS-FPL-3501	Fundamental wood properties	Madison, Wisconsin	IV, A-5-a
FS 3 5-2 (FPL)	FS-FPL-3502	Properties of wood-base and related materials	Madison, Wisconsin	IV, A-5-b
FS 3 5-3 (FPL)	FS-FPL-3503	Analytical mechanics	Madison, Wisconsin	
FS 3 5-4 (FPL)	FS-FPL-3504	Research equipment and method development	Madison, Wisconsin	
FS 3 5-5 (FPL)	FS-FPL-3505	Design criteria	Madison, Wisconsin	IV, A-5-c
FS 3 5-6 (FPL)	FS-FPL-3506	Structural utilization	Madison, Wisconsin	IV, A-5-d
FS 3 5-7 (FPL)	FS-FPL-3507	Packaging	Madison, Wisconsin	IV, A-5-e
		REGIONAL RESEARCH		
FS 3 6-1 (SE)	FS-SE-3601	Utilization improvement, SE	Asheville, N. C.	IV, A-2-c
FS 3 6-2 (SE)	FS-SE-3602	Characterization of southern hardwoods and associated species	Athens, Georgia	
FS 3 6-3 (SE)	FS-SE-3603	Southern hardwood utilization	Athens, Georgia	
FS 3 6-4 (CS)	FS-CS-3601	Utilization improvement, CS	Columbus, Ohio	IV, A-2-c
FS 3 6-5 (CS)	FS-CS-3602	Using Central States timber	Carbondale, Illinois	
FS 3 6-6 (NE)	FS-NE-3601	Utilization improvement, NE	Upper Darby, Pa.	
FS 3 6-7 (ITF)	FS-ITF-3601	Timber Utilization, Tropics	Rio Piedras, P.R.	
FS 3 6-8 (LS)	FS-LS-3601	Timber characterization and processing	Wausau, Wisconsin	
FS 3 6-9 (LS)	FS-LS-3602	Utilization improvement, LS	St. Paul, Minnesota	
FS 3 6-11 (PNW)	FS-PNW-3601	Utilization improvement, PNW	Portland, Oregon	
FS 3 6-13 (PSW)	FS-PSW-3601	Utilization improvement, PSW	Berkeley, California	
FS 3 6-15 (INT)	FS-INT-3601	Utilization improvement, INT	Ogden, Utah	IV, A-2-c

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FS 3 6-17 (RM)	FS-RM-3601	Utilization improvement, RM	Fort Collins, Colorado	IV, A-1-b, A-2-3
FS 3 6-19 (SO)	FS-SO-3601	Utilization improvement, SO	New Orleans, La.	IV, A-1-b, A-2-a A-2-c, A-2-e
		FOREST ENGINEERING RESEARCH		
FS 3 7-1 (INT)	FS-INT-3701	Engineering systems for steep mountain forestry	Bozeman, Montana	IV, B-1
FS 3 7-2 (LS)	FS-LS-3701	Engineering systems for northern hardwoods	Houghton, Michigan	
FS 3 7-3 (SO)	FS-SO-3701	Engineering systems for intensive forest management	Auburn, Alabama	
FS 3 7-4 (PNW)	FS-PNW-3701	Engineering systems for heavy timber stands in the Pacific Northwest and Alaska	Seattle, Washington	IV, B-2, B-3
FS 3 7-5 (NE)	FS-NE-3701	Engineering systems for Appalachian type forestry	Morgantown, W. Va.	
		P.L. 480 PROJECTS		
E8-FS-9		Factors affecting the impregnability of wood	Helsinki, Finland	
E8-FS-10		Moisture-temperature-time-strength relations, etc.	Helsinki, Finland	IV, A-5-f
E8-FS-18		Accessibility studies of cellulose fiber	Helsinki, Finland	IV, A-4-f
E8-FS-39		Aerobic bacterial degradation of lignin	Helsinki, Finland	IV, A-4-e
S8-FS-1		Collection of wood samples, etc. from forest trees of Peru	Lima, Peru	IV, A-1-f
A17-FS-2		Investigation and evaluation of factors influencing the absorption, etc. in tropical timber	Sholashahar, Chittagong, E. Pakistan	
A17-FS-7		Collection of wood samples, etc. from trees in East Pakistan	Sholashahar, Chittagong, E. Pakistan	
A7-FS-3		Working qualities of Indian timbers	Dehra Dun, India	IV, A-2-i

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CPO	FS			
FS 4 1	FS 4 1	FOREST SURVEY		V
FS 4 1-1 (NOR)	FS-NOR-4101	Forest Survey-NOR	Juneau, Alaska	V, A-1
FS 4 1-2 (PNW)(R)	FS-PNW-4101(Rev.)	Forest Survey-PNW	Portland, Oregon	V, A-1
FS 4 1-3 (PNW)	FS-PNW-4102	Survey Techniques-PNW	Portland, Oregon	V
FS 4 1-4 (PSW)	FS-PSW-4101	Forest Survey-PSW	Berkeley, California	V, A-1
FS 4 1-5 (INT)	FS-INT-4101	Forest Survey-INT	Ogden, Utah	V, A-1,4
FS 4 1-6 (LS)	FS-LS-4101	Forest Survey-LS	St. Paul, Minnesota	V, A-1,7
FS 4 1-7 (NE)	FS-NE-4101	Forest Survey-NE	Upper Darby, Pennsylvania	V, A-1,3
FS 4 1-8 (SO)	FS-SO-4101	Forest Survey-SO	New Orleans, Louisiana	V, A-1,5,6
FS 4 1-9 (SE)	FS-SE-4101	Forest Survey-SE	Asheville, North Carolina	V, A-1,5
FS 4 1-10 (WO)	FS-WO-4101	Forest Survey Techniques-WO	Washington, D. C.	V, A-2
FS 4 1-11 (CS)	FS-CS-4101	Forest Survey-CS	Columbus, Ohio	V, A-1
FS 4 2	FS 4 2	FOREST ECONOMICS		V
FS 4 2-1 (PNW)	FS-PNW-4201	Production Economics-PNW	Portland, Oregon	V, B-5,12
FS 4 2-2 (PNW)	FS-PNW-4202	Multiple Use Economics-PNW	Portland, Oregon	V, B
FS 4 2-4 (PSW)	FS-PSW-4201	Production Economics-PSW	Berkeley, California	V, B-2
FS 4 2-5 (PSW)	FS-PSW-4202	Multiple Use-PSW	Berkeley, California	V, B-2
FS 4 2-7 (INT)	FS-INT-4201	Production Economics-INT	Ogden, Utah	V, B
FS 4 2-8 (INT)	FS-INT-4202	Multiple Use Economics-INT	Ogden, Utah	V, B
FS 4 2-9 (RM)	FS-RM-4201	Watershed Economics-RM	Flagstaff, Arizona	V, B-9
FS 4 2-11 (LS)	FS-LS-4201	Production Economics-LS	St. Paul, Minnesota	V, B-6
FS 4 2-12 (LS)	FS-LS-4202	Small Woodland Ownership-LS	St. Paul, Minnesota	V, B-8
FS 4 2-13 (CS)	FS-CS-4201	Production Economics-CS	Columbus, Ohio	V, B
FS 4 2-14 (CS)	FS-CS-4202	Small Woodland Ownership-CS	Columbus, Ohio	
FS 4 2-15 (SO)	FS-SO-4201	Production Economics-SO	New Orleans, Louisiana	V, B
FS 4 2-16 (SO)	FS-SO-4202	Small Woodland Ownership-SO	New Orleans, Louisiana	V, B
FS 4 2-18 (NE)	FS-NE-4201	Timber Production Economics-NE	Upper Darby, Pennsylvania	V, B-2,7
FS 4 2-19 (NE)	FS-NE-4202	Small Woodland Ownership-NE	Upper Darby, Pennsylvania	V, B-1
FS 4 2-22 (SE)	FS-SE-4201	Production Economics-SE	Asheville, North Carolina	V, B-3,4
FS 4 2-25 (WO)	FS-WO-4202	Forest Finance-WO	Washington, D. C.	V, B-10,11

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CPO	FS			
FS 4 3	FS 4 3	FOREST PRODUCTS MARKETING		V
FS 4 3-1 (PNW)	FS-PNW-4301	Marketing-PNW	Portland, Oregon	
FS 4 3-2 (PSW)	FS-PSW-4301	Marketing-PSW	Berkeley, California	
FS 4 3-3 (INT)	FS-INT-4301	Marketing-INT	Ogden, Utah	
FS 4 3-4 (RM)	FS-RM-4301	Marketing-RM	Fort Collins, Colorado	
FS 4 3-5 (LS)	FS-LS-4301	Marketing-LS	Duluth, Minnesota	V, C-4
FS 4 3-6 (CS)	FS-CS-4301	Marketing Practices-CS	Berea, Kentucky	V, C-5
FS 4 3-7 (CS)	FS-CS-4302	Marketing Development-CS	Carbondale, Illinois	V, C-2,8
FS 4 3-8 (SO)(R)	FS-SO-4301(Rev.)	Marketing-SO	New Orleans, Louisiana	
FS 4 3-10 (NE)	FS-NE-4302	Marketing Development-NE	Princeton, West Virginia	V, C-3,4,5,6,7
FS 4 3-11 (SE)	FS-SE-4301	Marketing-SE	Asheville, North Carolina	
FS 4 3-13 (WO)	FS-WO-4301	Requirements-WO	Washington, D. C.	V, C-1,2
		Public Law 480 Projects (Forest Survey)		
E8-FS-32		Improved forest survey methods	Helsinki, Finland	V
E8-FS-40		Regional comparisons between the actual cuttings, cutting plans, growth, and forest resources. Theory, interpretation and analysis of selected countries.	Helsinki, Finland	

$5 mill spend 7 350,000 on marina &
clean up of Rec site.